1963

RESEARCH HIGHLIGHTS

OF THE

NATIONAL BUREAU OF STANDARDS

NNUAL REPORT

The groups to be served by the specialized services of the National Bureau of Standards were well defined by the Congress at the time the Bureau was founded. The Committee on Coinage, Weights and Measures in recommending to the House of Representatives in May of 1900 that a National Bureau of Standards be established, said:

> **"It is therefore the unanimous opinion of your committee that no more essential aid could be given to manufacturing, commerce, the makers of scientific apparatus, the scientific work of the Government, of schools, colleges and universities, than by the establishment of the institution proposed in this bill."**

This statement, which provides an enduring focus for the activities of the Bureau, will be engraved in stone in the lobby of the Administration Building at the new laboratory site near Gaithersburg, Maryland.

A. V. Astin, *Director*,

National Bureau of Standards.

UNITED STATES DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*
J. Herbert Hollomon, *Assistant Secretary for Science and Technology*
NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

1963
Research Highlights
of the
National Bureau of Standards

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1. GENERAL REVIEW

During the past year the National Bureau of Standards continued efforts to focus and strengthen its technical program in support of the Nation's technological advancement and economic growth. Major areas of effort were basic measurement standards, standard reference data, engineering measurement standards, standard reference materials, radio propagation, data-processing systems, and building research.

In this program the Bureau was concerned primarily with research and technical services in the general field of physical measurement—a field of basic importance to progress in commerce, industry, and science. Commerce involves exchange of goods and services, and standards of physical measurement provide a basis for determining both quantity and quality in commercial exchange. Similarly, progress in science and in the application of science to technology is based on the exchange of information, particularly quantitative data, derived by the use of measurement standards. Thus, the Bureau strives to advance measurement science and to further its application in order to facilitate the reliable, efficient exchange of quantitative data in science and engineering and of technological products and services in commerce.

Within the field of physical measurement, the Bureau is concerned with four distinct but related types of standards: (1) Standards for the physical quantities and units basic to the physical sciences and engineering; (2) standards for the determination of quantity, quality, or performance of the technological products and materials of commerce; (3) standard reference data; and (4) standard reference materials for use in controlling chemical processes and maintaining the accuracy of apparatus and equipment.

Through the years, in order to meet specific needs of the Government, the Bureau has also undertaken responsibility within Government for operating central research and technical service programs in special areas. Such programs are carried on by the Central Radio Propagation Laboratory, the Data Processing Systems Laboratory, and the Building Research Division.

In addition to the above mission-oriented activities, the Bureau conducts a broad program of exploratory or background research in the physical sciences. The primary purpose of this work is to maintain and strengthen the general scientific competence of the Bureau staff so that the Bureau can keep abreast of new developments in many fields, select the most effective techniques for solving problems, and utilize quickly the results of scientific work elsewhere. At the same time, however, the results of this research may be expected to contribute substantially to the Nation's scientific progress.

This report attempts to present the highlights of the Bureau's program for the fiscal year 1963. In Section 2, the body of the report, studies and achievements from the various fields in which the Bureau is active have been selected for brief presentation. However, the breadth of the program and diversity of projects may make it difficult for the reader to obtain a coherent picture of the year's activity. The remainder of Section 1 is therefore devoted to a brief summary of the more important accomplishments and activities of the year.

BASIC MEASUREMENT STANDARDS

The National Bureau of Standards is responsible for developing and maintaining the national standards of physical measurement upon which all measurements in this country are based. As part of its measurement responsibility, the Bureau must also see that these standards are made available to science, industry, and commerce through suitable calibration services.

During the last year the Bureau continued to be faced with the demands of a rapidly expanding technology for greater accuracy and range in the calibration services provided to laboratory, plant, and shop. A considerable portion of the research effort was therefore directed toward the extension of precise standards and measurement techniques to new areas of science and technology, and to new accuracies. Services added during the year included calibration of microwave noise sources, at 9.0, 9.8, and 11.0 Gc/s, and power calibration of bolometer and bolometer-coupler units.

Insofar as possible, the Bureau restricted its own calibration work to master standards and high-precision instruments, leaving the calibration of lower-echelon standards to the other standards laboratories that have been set up by industry and the military services. Even so, the volume of NBS calibration services continued at a high level (table 1). Over 75,000 calibrations, having a total value of more than $2 million, were performed for Government and industry.

In an effort to cope more effectively with the calibration load, further efforts were made to automate calibration procedures so that the output data appear directly on punched cards or tape, ready for computer reduction. Two devices for this purpose were developed during the year: an automatic thermocouple comparator and a data-recording assembly for measurement of thermal emittance standards.

For several years the Bureau has been conducting a research program looking toward the development of procedures for calibrating master gage blocks on a regular basis to 1 part in 10 million. This work was begun, at the request of machine tool manufacturers, in order to meet the stringent calibration requirements imposed by the use of increasingly smaller tolerances in industry. Attainment of the program's objective requires development of both highly stable gage blocks and ultra-precise measuring techniques. Two types of gage blocks have now been developed which are dimensionally stable to better than one 10-millionth of an inch per year, and seven additional types have been produced which are stable to between one

TABLE 1. *Summary of calibration services*

Area of Bureau activities	Representative items	Public		Government		Totals	
		Number of items	Fees	Number of items	Fees	Number of items	Fees
Electricity	Electrical instruments, standard cells, resistance, reactance and capacitance standards, d-c to 30 kc/s.	9,695	$179,887	2,537	$41,318	12,232	$221,205
Metrology	Light and color standards, photographic lenses, gage blocks and other length standards, refractive index standards, sieves, mass standards, track scales, capacity standards.	41,057	376,877	3,510	104,373	44,567	481,250
Heat	Resistance and liquid-in-glass thermometers, thermocouples, pyrometers.	7,765	170,911	938	41,154	8,703	212,065
Radiation Physics	Neutron sources and instruments, X-ray and gamma-ray protective materials and instruments, gamma-ray sources, alpha-ray sources, radioactive materials.	190	10,233	231	9,670	421	19,903
Mechanics	Acoustic instruments, proving rings, load cells, dynamometers, pressure standards, water current meters.	4,056	167,260	1,590	70,857	5,646	238,117
Building Research	Thermal conductivity	38	5,520	24	3,745	62	9,265
Radio Standards	Electrical and electronic instruments and standards in radio, ultra-high-frequency, microwave ranges.	2,131	135,294	1,599	885,191	3,730	1,020,485
Total		64,932	1,045,982	10,429	1,156,308	75,361	2,202,290

and two 10-millionths of an inch per year. In the measurement part of the program, an investigation was begun to determine the thickness of the molecular film between joined gage blocks, which in practice must be considered as a part of the length of the blocks. In support of this research, theory was developed which provided new knowledge about the behavior of light beyond a surface normally thought to be totally reflective.

In research to develop more accurate methods of measuring long distances, promising results were obtained through use of a helium-neon laser as the infrared light source for a Michelson interferometer. With this apparatus, interference fringes—normally visible over an optical path of not more than 2 meters—were obtained over an optical path of approximately 200 meters. Thus use of a gaseous laser source appears to offer a means for measuring long distances to high accuracy. Work is now underway to stabilize the laser equipment so that interferometric calibrations of length-measuring devices may be made with the laser.

The accurate measurement of spectral irradiance has assumed increasing importance in connection with studies of the irradiance to which space vehicles will be subjected. During the year a new standard of spectral irradiance was developed in the form of a 200-watt quartz-iodine lamp with a coiled tungsten filament operating at about 3000 °K. The new standard operates without auxiliary optics and provides relatively high spectral irradiances.

Progress was made in research efforts seeking to develop standards and measurement techniques for very high pressures. For use as a fixed point in calibration work, the freezing pressure of mercury at 0 °C was determined to be 109,722 lb/in.^{2}, accurate to within $\pm$30 lb/in.^{2}. A new piston gage was under construction for use in a more accurate determination of the phase transition of bismuth between 365,000 and 370,000 lb/in.^{2}. This transition has been serving as the principal calibration point in the ultra-high-pressure range.

A number of advances were made in the field of electrical measurement. For example, a new differential a-c–d-c transfer standard was developed to meet the growing need for greater speed and accuracy in measuring a-c voltages at audiofrequencies. Unlike older forms of a-c–d-c transfer instruments, in which successive comparisons were required, this instrument can be used for the simultaneous comparison of an unknown a-c voltage with a known d-c voltage. It provides a usable precision of 10 parts per million.

A permanent adjustable standard of magnetic susceptibility was designed and was incorporated into a magnetic susceptibility bridge of high accuracy and sensitivity. Other apparatus was constructed for determining absolute magnetic susceptibilities down to liquid helium temperatures.

A microwave phase-shift measuring system was developed that is capable of measuring phase shift to an accuracy within 0.01 degree. The system is now ready for use in a national microwave phase-shift calibration service.

Research continued on atomic standards of frequency and time. The United States Frequency Standard, which is derived from a natural fre-

quency of the cesium atom, is now accurate to better than one second in 3,000 years. During the year one of the two cesium beam frequency standards that have been used in maintaining the national standard was converted to a thallium beam for the purpose of evaluating a thallium transition as the standard of frequency, and it appears that an improvement of one order of magnitude in accuracy over that of cesium can be expected. Also, a new cesium beam frequency standard was completed which promises to have a precision about twice that of the other cesium standard now in use. The United States Frequency Standard provided a basis for the establishment of an NBS atomic time scale. The NBS atomic time was related to the time pulses of NBS radio station WWV, to the atomic time kept by the Naval Observatory, and to the time pulses of the Loran-C master station at Cape Fear, N.C.

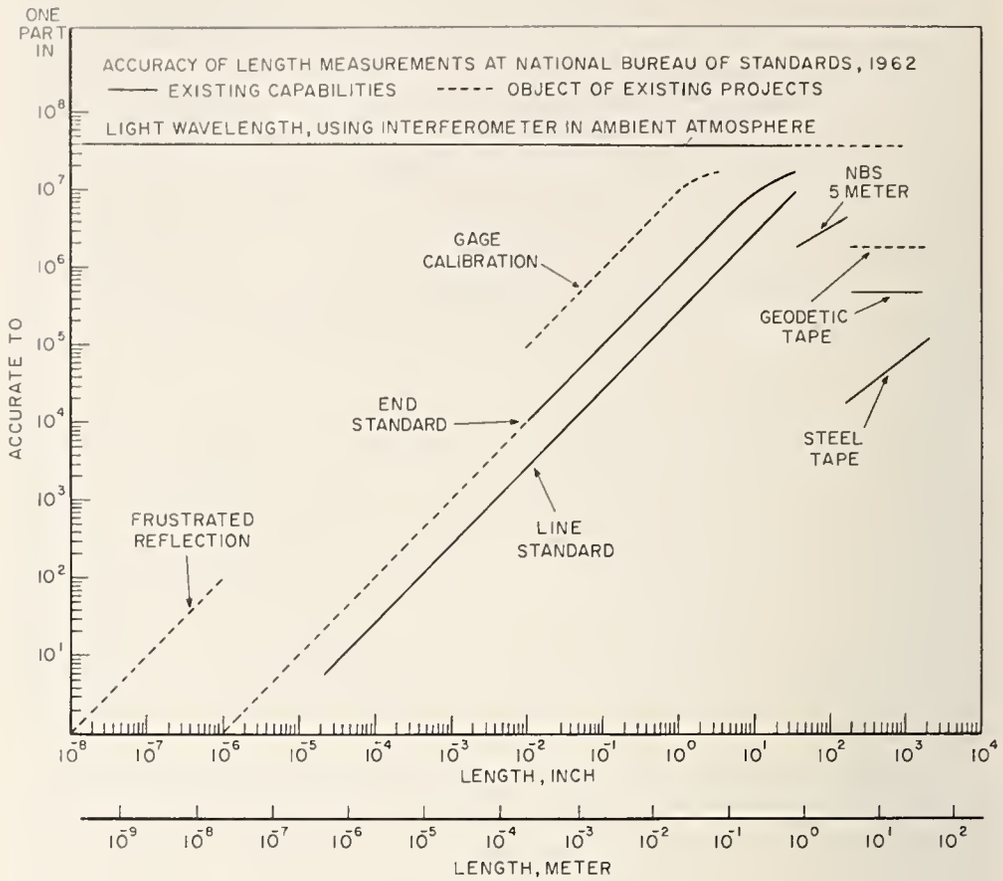
The Bureau continued to cooperate closely with the National Conference of Standards Laboratories. This Conference and its continuing committees bring together representatives from military, industrial, and university standards laboratories, to promote cooperative action on common problems of the management and operation of measurement standards and calibration laboratories. In August 1962 the Bureau was host to the first national meeting of this organization at the NBS Boulder Laboratories. Over 600 persons attended the Conference, the proceedings of which were published by the Bureau.

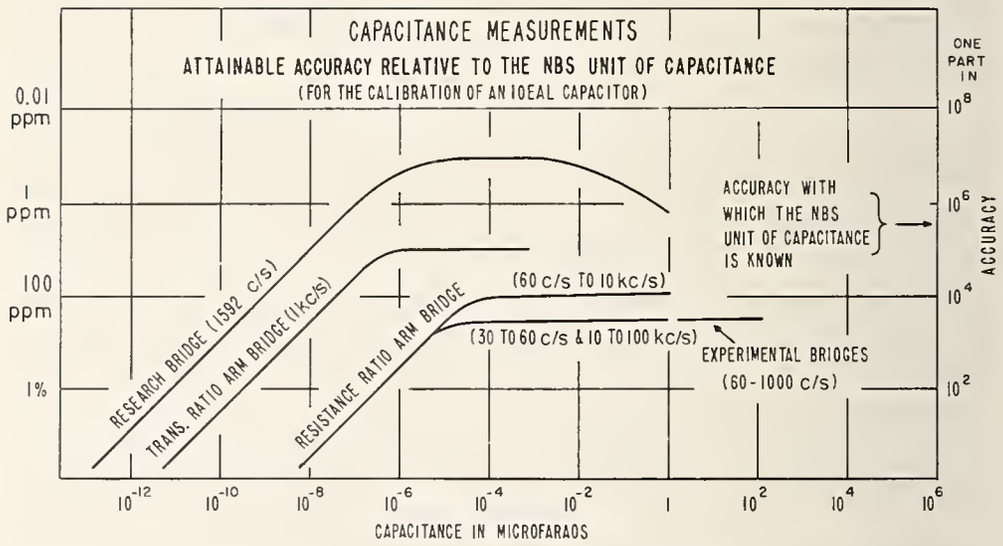
The Bureau also cooperated in an interservice measurement audit which is designed to promote measurement agreement among the military services. Items being measured include resistance and capacitance standards, a frequency meter, an optical polygon, and a vibration pickup. Results of tests on these items by the Bureau, the Army, Navy, Air Force, and Sandia Corporation representing the Atomic Energy Commission, will be analyzed by the Air Force.

A series of precision measurement seminars, designed to provide an opportunity for qualified senior people from other organizations to benefit from the Bureau's long experience in certain measurement areas, was announced during the year. Attendance at these seminars, in the fields of length, acoustics, frequency comparison techniques, attenuation at communications frequencies, and precision and accuracy, was limited to permit detailed individual participation. Registrants were selected from Government, industry, and university laboratories.

During the year a uniform format for reporting the results of calibrations and tests was adopted. All such results are now issued in report form, supplemented by a letter of formal certification when required by law or special conditions. Generally the reports include more useful discussion and evaluation of the uncertainties involved than was formerly provided.

The preparation of charts showing NBS capabilities in various measurement areas was continued. Several of these charts are reproduced on page 6.





Charts depicting NBS capabilities in the measurement of length (top) and capacitance (bottom).

STANDARD REFERENCE DATA

During 1963 a considerable portion of the Bureau's research effort was devoted to the development of standard reference data in the physical sciences. In addition a number of data centers for compilation and storage of critically evaluated data were operated in such areas as chemical thermodynamics, atomic transition probabilities, atomic cross sections, ceramic phase equilibria, and cryogenics. During the year, the Data Center on Atomic Collision Cross Sections completed a survey of all literature reporting cross sections for two-body collisions involving a free electron. This Center is now providing bibliographic searches for the general scientific community and is preparing a complete bibliography by subject classification. The Data Center on Atomic Transition Probabilities published a bibliography containing a complete listing of pertinent articles in this field and had almost completed a critical evaluation of transition probability data on the first 10 elements.

The Cryogenic Engineering Data Center continued to serve as a clearing house for research and development literature on cryogenics. During the year some 4100 new references were coded and entered into the Center's storage and retrieval system. Special attention was given to low-temperature data on the properties of solids and fluids; 1500 of the new entries were in these categories. A number of extensive bibliographies on properties of materials were compiled, and an estimated 20,000 items of NBS literature were distributed in response to some 1500 requests.

An important area of research was concerned with the application of the wall-stabilized arc for the measurement of transition probabilities and to gain a better understanding of high-temperature plasma phenomena. The shifts and widths of several oxygen lines were measured and the results were found to be in good agreement with recent theories on line broadening in dense plasmas.

In other studies using a gas-stabilized arc, transition probabilities for 105 lines in the spectrum of neutral atomic iron were redetermined to higher precision than in previous work.

Apparatus was constructed to study the variation in dielectric constant and relaxation time for liquids and supercooled liquids at pressures up 2000 atmospheres and at temperatures from liquid nitrogen temperature (−196 °C) to about 50 °C. By suitable choices of temperature and pressure, measurements with this apparatus may be conducted at constant density in order to provide more definitive tests of dielectric theory.

A microwave spectrometer which can be operated at temperatures up to 1000 °C was constructed and applied successfully to several problems in high-temperature chemistry. This instrument permits the extension of powerful microwave techniques to the identification and structure determination of molecules and radicals that are present in high-temperature systems. Spectra for such molecules as aluminum monofluoride and aluminum monochloride, which do not exist at room temperature but which are important constituents in rocket combustion systems, have been detected and analyzed.

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New information on the atomic energy levels of the rare gases helium, neon, and argon was obtained in a series of independent experiments which utilized both electron and photon interactions. Optical photons in the far ultraviolet, produced by the accelerated electrons in the Bureau's 180-Mev synchrotron, were used in studies of the absorption properties of the three gases, which resulted in the discovery of a number of new atomic energy levels in these gases. These findings were confirmed in observations on energy losses of electrons scattered by the gases and in theoretical studies of their ultraviolet absorption properties.

Determination of the structure of carbon suboxide (C_3O_2) resolved a scientific controversy of 30 years' standing. Through analysis of a high-resolution infrared absorption spectrum, conclusive evidence was obtained that the molecule is a straight chain consisting of three carbon atoms with an oxygen atom at each end. Since 1933, when the carbon suboxide molecule was reported to have a dipole moment, indicating some sort of bent structure, molecular spectroscopists have been divided in support of linear and nonlinear configurations. Valence theory predicts the linear form, but earlier studies, handicapped by inadequate resolution and impure samples, provided inconclusive and contradictory results. Finally, the Bureau obtained new evidence by using ultra-high-resolution techniques to determine the rotational fine structure of a band in the 3-micron region.

National Standard Reference Data System. In June 1963, the Office of Science and Technology, acting on a recommendation of the Federal Council for Science and Technology, established a National Standard Reference Data System (NSRDS) to provide critically evaluated data in the physical sciences on a national basis. The Bureau was given responsibility for administering the System, which will centralize a large part of the present data-compiling activities of a number of Government agencies.

The aim of the NSRDS is to develop a storehouse of standard reference data to assist in the advancement of science, technology, and the national economy. This result is to be achieved through a broad-based, comprehensive effort by scientists both in and outside the Government.

The Bureau, as well as other organizations in this country and abroad, has been active in the compilation of standard reference data for many years. However, in view of the great accumulation of unevaluated data over the past few years, the present accelerated production of new data, and the urgent needs of American science and industry, it has become apparent that a substantially greater effort, planned and coordinated on a national basis, is needed.

The National Standard Reference Data System will consist of a National Standard Reference Data Center at the Bureau, and various other Standard Reference Data Centers in other Government agencies and at universities, research institutes, and other non-Government organizations. In order for such centers to be a part of the NSRDS, they will be required to meet quality standards established by the Bureau. However, the independent and operational status of existing critical data projects will be encouraged.

An Advisory Board will review and recommend policy relative to the operation of the NSRDS. It will include, among others, representation from the National Academy of Sciences, National Science Foundation, and Federal agencies engaged in research and development.

The NSRDS will be conducted as a decentralized operation across the country, with central coordination by the Bureau. According to present plans, the data input will come from scientists in many different locations who will comprehensively review the literature in their fields of specialization and will critically evaluate the data it contains. The evaluated data will be classified and stored at the Bureau and will be disseminated through a series of services tailored to user needs in science and industry. In choosing work to be undertaken, the Bureau will be assisted by the Advisory Board, interagency panels, expert consultants in the subject-matter areas, and working committees of the scientific and engineering societies and industry associations that are active in the field of critical data.

ENGINEERING MEASUREMENT STANDARDS

The Bureau cooperates extensively with recognized standardizing bodies in the development of codes, specifications, standards of practice, and methods of test for technological devices, products, and services. In general, the Bureau contributes by conducting research to provide test methods, data on materials, and measurement standards; the sponsoring organization supplies other technical data and promulgates the finished documents in the form of codes, specifications, or engineering standards. The Bureau is in a position to provide material assistance in this field because of the active participation of its staff members in the work of numerous technical societies and standardization groups such as the American Standards Association, the American Society for Testing and Materials, and the Society of the Plastics Industry.

The Bureau also plays an active role in the development of government purchase specifications. During fiscal 1963, at the request of the General Services Administration, the Bureau accepted responsibility for preparing and maintaining two additional Federal Specifications, making a total of 154 for which it now has this responsibility. The Bureau also reviewed approximately 600 proposed specifications both for GSA and for other agencies to determine their suitability for use by the Federal Government.

In June 1963, the scope of the Bureau's program in technological standards was increased with the transfer of the Commodity Standards Division of the Office of Technical Services, U.S. Department of Commerce, to the National Bureau of Standards. The transferred activity provides assistance to industry, business, and consumers in the development and acceptance of voluntary trade standards that define quality levels for products and aid in holding variety to a minimum.

In the last year, many experimental data were obtained for developing and improving building codes, standards for building materials, and methods of testing building materials and equipment. Typical of this work were investigations of the creep and shrinkage of structural lightweight concrete,

studies of methods of waterproofing underground structures, and work to extend methods of measuring thermal emittance and thermal conductivity to higher temperatures.

Fiberglass-reinforced plastics are being employed for many structural purposes today. However, weather exposure decreases their strength and light-transmitting characteristics. During 1963 the Bureau developed a sensitive colorimetric method for determining degradation of fiberglass-reinforced polyester plastics. This method provides a rapid, reproducible means for predicting durability.

Laboratory investigations leading to the development of a testing and rating method for refrigerated trucks were carried out under the joint sponsorship of the U.S. Department of Agriculture, the Truck Body and Equipment Association, and the Bureau. An apparatus for simulating the effect of solar radiation on the cooling load of stationary refrigerated trucks was designed and constructed. It was found that the air and moisture transmission through the body was significantly different for different constructions, and that the effect of solar radiation could be satisfactorily accounted for by a correction factor to the steady state heat transfer.

In other research for development of test methods, a technique was devised for using a digital computer to analyze the microstructure of metals and alloys. This computer technique takes the place of tedious manual operations in determining the size, shape, and number of crystals or grains found in photomicrographs of metal or alloy structures. In this way analyses are accomplished up to a thousand times more quickly than has been possible with conventional manual methods. Thus far the technique has been used in studies of the graphite content of cast iron and of niobium-tin phases in experimental superconductor alloys. The rapid, accurate results obtained in these studies demonstrate the feasibility of employing computer programs in micrographic analyses, and suggest the use of the technique in other areas, such as petrography, microbiology, astronomy, and photogrammetry.

A new three-terminal dielectric cell was completed and used to make precise dielectric constant measurements by the two-fluid method which requires no electrodes. With this apparatus the dielectric constant of a disk specimen can be obtained to within better than 200 parts per million between 100 cycles per second and 50 kilocycles per second.

A scheme of color tests was developed for identifying the five antioxidants commonly used in styrene-butadiene synthetic rubbers. These antioxidants include naphthylamine and diphenylamine compounds, styrenated phenols, and alkylated arylphosphites. By using specified successive tests involving two or more of a group of 12 reagents, the uncertainty of distinguishing between similar colors obtained with a single test was overcome.

An improved analytical procedure was developed for measuring the thiosulfate radical remaining in photographic film after processing. Such tests are routinely conducted to assure conformance to microfilming specifications. The new procedure reveals two or three times as much residual thiosulfate

as does the current standard analytical method which has been in use for the past 30 years.

During fiscal year 1963, the Bureau tested 53,877 items ranging from dry cells to building materials (table 2). Most of the tests were on items purchased by other Federal agencies that lacked the facilities to make the tests themselves.

STANDARD REFERENCE MATERIALS

During fiscal year 1963 the Bureau distributed 72,074 samples of standard materials, having a value of $551,264, to other laboratories (table 3). Nearly 600 different standard materials are at present available—principally chemicals, ceramics, metals, and radioactive nuclides. New standard materials added during the year included radioactivity standards of iodine 125 and cerium 139; two polystyrene molecular weight standards; five portland cement standards; a standard soda-lime-silica glass; and various alloys for spectroscopic standardization. All are certified either for chemical composition or with respect to a specific physical or chemical property such as melting point, viscosity, or color.

In research to develop new standard materials, a technique known as dielectric cryometry was devised for precise determinations of purity. In

A new method of producing glass with controlled light scattering properties led to these prototype turbidity standards. They are now being studied as possible replacements for the less durable plastic and liquid standards presently in use. **(See p. 11.)**

TABLE 2. *Summary of testing services*

Area of Bureau activities	Representative items	Public		Government		Totals	
		Number of items	Fees	Number of items	Fees	Number of items	Fees
Electricity	Dry cells, hearing aid batteries, storage batteries			518	$6,880	518	$6,880
Metrology	Lamps			2,401	40,000	2,401	40,000
Analytical and Inorganic Chemistry.	Chemical analysis	13	$2,604	191	4,988	204	7,592
Mechanics	Mechanical devices			1,857	18,170	1,857	18,170
Organic and Fibrous Materials	Paper, textiles, rubber, leather and plastic products	18	4,796	5,537	154,500	5,555	159,296
Metallurgy	Metals and alloys	1,719	18,062	30	18,148	1,749	36,210
Mineral Products	Ceramic products, glass			13	1,950	13	1,950
Building Research	Building materials, air filters, fire extinguishers, heating and air conditioning equipment, paints and other surface coatings.	6	867	1,654	48,925	1,660	49,792
	Cement	2,059	51,412	16,657	622,706	18,716	674,118
	Concrete and concreting materials			12,644	157,821	12,644	157,821
Physical Chemistry	Synthesis of sugar and related products	7,385	7,680	1,175	2,844	8,560	10,524
Total		11,200	85,421	42,677	1,076,932	53,877	1,163,353

TABLE 3. *Standard samples issued*

Area of Bureau activities	Description of samples	Public		Government		Totals	
		Number of samples	Value	Number of samples	Value	Number of samples	Value
Metrology	Glass filters	115	$5,750	5	$250	120	$6,000
	Resolution test charts	13,258	2,652	496	99	13,754	2,751
	Calibrated glass spheres	246	2,336	28	267	274	2,603
	Photometric standards	436	21,872	47	2,656	483	24,528
	Spectrophotometric standards	62	6,572	11	1,191	73	7,763
	Color temperature standards	55	2,383	10	465	65	2,848
	Reflectance standards	136	2,780	18	314	154	3,094
	Opacity standards	96	3,055	.....	.....	96	3,055
	Gloss standards	121	2,396	2	52	123	2,448
	Signal glass limit standards	121	7,338	3	198	124	7,536
	Haze standards	226	3,880	.....	.....	226	3,880
	Radiance standards	126	39,625	38	11,410	164	51,035
	Irradiance standards	39	3,081	20	1,580	59	4,661
Radiation Physics	Radioactive samples	375	10,364	224	6,139	599	16,503
Chemistry	Hydrocarbon blends	50	600	.....	.....	50	600
	Hydrocarbon	97	3,061	27	657	124	3,718
	Cells	22	3,190	2	450	24	3,640
	Spectrographic	5,801	99,187	536	9,508	6,337	108,695
	Composition	22,711	138,891	1,335	7,548	24,046	146,439
	Metal-organic material	461	4,610	74	740	535	5,350
	Sucrose and dextrose	362	1,448	57	228	419	1,676
	Labeled carbohydrates	7,385	7,680	1,095	1,192	8,480	8,872
	Special nuclear standards	1,516	32,641	118	3,361	1,634	36,002
Mechanics	Viscosity oils	977	15,921	143	2,255	1,120	18,176
Polymers	Standard fading	499	6,455	31	204	530	6,659
	Reference paper	445	1,780	19	76	464	1,856
	Rubber	6,396	33,962	29	259	6,425	34,221
	Phosphor reference	77	231	35	105	112	336
	Polystyrene	153	2,316	17	256	170	2,572
Metallurgy	Unalloyed titanium	98	980	6	60	104	1,040
	Gas analysis	250	2,500	15	150	265	2,650
	Standard thickness samples for electroplated coatings	1,712	17,733	.....	.....	1,712	17,733
Inorganic Solids	Soda-lime-silica glass	47	1,880	2	80	49	1,960
Building Research	Surface flammability	85	680	.....	.....	85	680
	Paint pigments	8	24	56	168	64	192
	Cement	2,748	8,570	263	922	3,011	9,492
Total		67,312	498,424	4,762	52,840	72,074	551,264

this method, measurements of the change in dielectric constants are used to determine the solid-liquid ratios corresponding to various freezing (or melting) temperatures of the substance studied. An advantage of the method is that it permits use of relatively small samples (4 to 10 ml) to determine purity.

In studies of phase changes in silica-metal oxide systems, a means was found for producing glasses having a controllable degree of light scattering. Glasses of this type are being evaluated as turbidity standards to replace the less durable plastic and liquid standards that are now in use.

Because of its reproducibility, the *p*H of solutions in alcohol-water solvents, determined with commercial electrometric *p*H equipment, is an important control variable in certain research operations as well as in industry and commerce. Until recently, however, *p*H numbers determined in the conventional way could be interpreted in terms of hydrogen ion concentration or activity only when the solvent medium was pure water. During 1963, a scale of *p*H (designated *p*H*) for methanol-water and ethanol-water media was shown to be practical, and procedures were devised for assigning standard values of *p*H* to reference solutions. The *p*H* determined experimentally bears a simple relation to dissociation constants and other thermodynamic quantities in the same medium and, as such, should have wide application in many branches of chemistry and biology.

SPECIAL CENTRAL MISSIONS

Radio Propagation. Within the Federal Government, the NBS Central Radio Propagation Laboratory (CRPL) has been given the central responsibility for collecting, analyzing, and disseminating information on the propagation of radio waves at all frequencies along the surface of the earth, through the atmosphere, and in outer space. To carry out this responsibility, it conducts research on the nature of the waves, the media through which they are transmitted, and the interaction of the waves with the media.

During 1963, ground-based studies of the ionosphere in the vicinity of the earth's equator were made by a scatter radar technique at the Jicamarca (Peru) Observatory of CRPL and of the Instituto Geofisico de Huancayo (Peru). This observatory, located on the magnetic equator near Lima, employs a 6-million-watt transmitter and a 22-acre antenna to transmit a very-high-frequency radio wave of extremely short duration to great heights. The antenna is also used to detect the faint reradiation of the pulsed radio wave by free electrons in the upper atmosphere. The primary function of the installation is to study the distribution of electron density with height out to 6,000 miles or more above the earth's surface.

In cooperation with the Instituto Geofisico de Huancayo, the Jicamarca Observatory made a series of measurements of the synchrotron radiation that was emitted by the manmade belt of high-energy electrons which formed as a result of the high-altitude nuclear detonation occurring above Johnston

Island in the Pacific on July 9, 1962. From these measurements, made at 30 and 50 megacycles per second, the number, energy spectrum, and decay rate of the electrons were derived—information that will help improve understanding of the physics of the upper atmosphere. The extremely high radar sensitivity available at Jicamarca also made possible the detection of radar echoes from Venus when the planet was observable from Lima during the first week of December 1962.

Data-Processing Systems. In the rapidly advancing field of automatic data processing, the Bureau serves the Federal Government as a center for research and services to promote more effective utilization of data-processing facilities within the Government. With the increasing variety and complexity of governmental applications of data processing, the scope of the research program in this field has correspondingly increased until it now utilizes the techniques of several scientific disciplines. Representative activities during the past year included exploration of the operational characteristics of new components to determine their suitability for computer circuitry, studies of the properties of materials used in new components, and development of techniques for extending automated procedures in areas such as the processing of scientific information. Studies were conducted on ultrathin ferromagnetic films as potential high-speed random access memory elements, and an investigation was begun of the technique of quantitative analysis of thin films by X-ray fluorescence. Research continued on simulation and characterization of semiconductor devices such as tunnel diodes and epitaxial transistors. In connection with this work, a counter circuit incorporating tunnel diode-transistor type of circuitry was developed that is capable of counting up to 80 megapulses.

Building Research. Studies were conducted in physics, chemistry, and engineering to develop new knowledge relating to building materials, equipment, and structures. For example, work was done on the reactions which take place in concrete upon setting, involving heats of formation of many compounds, and on the reactions which take place after setting, involving the corrosion of concrete reinforcements. Other typical investigations dealt with methods of controlling unwanted fires, heat transfer in structures, mechanical systems for buildings, metallic building materials, and properties of asphalts. During the year, experimental results were obtained which support the colloidal theory of asphalt: the presence of an electric charge on dispersed asphalt particles was detected and measured. Although the theory of the colloidal nature of asphalts has received wide support since its proposal many years ago, until this finding little if any experimental evidence to support the theory had been reported.

CONSULTING SERVICES

To a considerable extent, the Bureau's consulting activities are a natural result of the broad scope of its program and the special competence of many of its staff in the physical sciences and engineering. Services of this kind

are rendered to other Federal agencies, to State and municipal governments, and to various industrial groups.

Consulting services to the Federal Government ranged from the supplying of specific technical information upon request to long-range projects that were within the NBS mission but were sponsored by other agencies. Many such projects were in the field of automatic data processing. For example, a portable peer-rating machine, which rapidly computes group ratings of individuals, was developed for the U.S. Army Personnel Research Office. At the request of the Office of Technical Services, U.S. Department of Commerce, a system was designed for mechanizing the preparation of announcement bulletins and indexes, inventory control, and storage and retrieval of documents. In work done for the Patent Office, a remote inquiry station was designed to permit easy and rapid communication between human operators at their respective locations and a central data processor, all of which might be located within one building or might be separated by hundreds or thousands of miles. Under the sponsorship of the Navy's Bureau of Supplies and Accounts, assistance was given in the development of an efficient system to procure and distribute the thousands of items required within the Naval establishment and to control their purchase, storage, and distribution. An information-handling system was designed for the Naval Intelligence Agency to provide an efficient, low-cost means of storing, searching, and retrieving intelligence data.

Consultative services were provided to the Weather Bureau on the transmission and processing of photographic and infrared data generated by the new weather satellites of the NIMBUS series. Systems analyses were continued to determine the feasibility of utilizing automatic data-processing techniques in the activities and operations of the Interstate Commerce Commission.

Assistance to State and municipal governments was principally in the field of weights and measures. Although the Bureau itself does not have regulatory powers, it offers technical advice and consultation to local regulatory bodies and it calibrates and adjusts State standards of weights and measures. A major medium of cooperation is the National Conference on Weights and Measures. Over 400 delegates from 39 states, Puerto Rico, and several foreign countries attended the 48th annual meeting of this Conference, held in Washington, D.C., June 10 to 14, 1963, under NBS sponsorship.

Important means of Bureau-industry cooperation were the Research Associate Plan and the donor program. Under the Research Associate Plan, technical, industrial, and commercial organizations can support work at the Bureau that is of special interest to them, yet of sufficient general interest to justify use of Government facilities. The work is done by research associates who are paid by the sponsor but otherwise function as members of the Bureau staff. At the present time the following groups are supporting research associates at the Bureau:

Sponsor	*Field of Activity*
American Dental Association	Dental research
American Electroplaters' Society	Galvanic effects associated with coating failure
	Properties of electrodeposited copper
American Society for Testing and Materials	Cement and concrete reference laboratory
American Standards Association	Codes, specifications, and standards
Asphalt Roofing Industry Bureau	Asphalt roofing research
Bone Char Research Project, Inc.	Studies of adsorption and adsorbents
Calcium Chloride Institute	Hydration of portland cement
NBS—Joint Committee on Chemical Analysis by Powder Diffraction Methods: ASTM, American Crystallographic Assoc., Institute of Physics (British), National Assoc. of Corrosion Engineers	Standard X-ray diffraction powder patterns
National Academy of Sciences–National Research Council	Atomic physics
Porcelain Enamel Institute	Porcelain enameled metals

The donor program was authorized in 1950 by Public Law 619 under which the Bureau may accept funds for the purpose of furthering its work. This arrangement permits individuals as well as technical, industrial, and commercial organizations to support work at the Bureau when the results are expected to be of value to the general public. During the past year, the following projects were supported by gifts:

Donor	*Field of Activity*
American Iron and Steel Institute	Durability of steel pilings
	Grant for standard samples program
Brown and Sharpe Manufacturing Co.	Gage block program
Corrosion Research Council of the Engineering Foundation	Durability of steel pilings
Edward Mallinckrodt, Jr.	Theoretical chemistry
Expanded Shale Clay and Slate Institute	Creep and shrinkage of concrete
International Business Machines	Gage block program
Link Aviation, Inc.	Gage block program
Pratt and Whitney	Gage block program
The Edward Orton Jr. Ceramic Foundation	Basic clay research

In the project sponsored by the American Iron and Steel Institute, the Bureau investigated the extent of corrosion in steel piling that had been driven into the ground. Data obtained from pilings which had been in service in different geographic locations for 7 to 40 years showed that the strength and useful life of the driven piling were not materially affected by corrosion, apparently because of the deficiency of oxygen in "undisturbed" natural soils. These findings are in sharp contrast to those of earlier corrosion studies in which metal specimens such as pipe lines that had been buried under "disturbed" soil conditions exhibited varying degrees of corrosion. The disparate results are attributed to the differences in oxygen content between the "undisturbed" piling environment and the "disturbed" pipeline environment. Studies are now being made to determine the reasons for this difference.

BACKGROUND RESEARCH

Study of the transitions that materials undergo at high pressures aids in defining interatomic forces and the perturbing effects of neighboring atoms on one another. During the year direct visual observations were made of phase transitions and other changes occurring in a variety of polymers subjected to extremely high pressures—up to one million pounds per square inch. The polymers were compressed between diamond anvils which served both as load-bearing surfaces and as light-transmitting media, and a microscope was focused onto the specimen through the diamond. By passing infrared and X-rays through the diamond pressure cell or by viewing the transformations through a microscope, it is possible to relate changes in crystal structures to changes in bond energies, force constants, and vibration frequencies.

Large single crystals of metals, semiconductors, and other materials are needed for many purposes in science and industry. However, single crystals of most materials of practical interest are difficult to grow. The Bureau has been making an effort to learn more about crystal-growing mechanisms through study of simpler substances. It was found that at very low temperatures large crystals of rare gases may be prepared and studied with many of the same techniques that have been used at higher temperatures on other substances. These gases are prototype molecular solids in which the forces among the molecules are so weak that they crystallize at low temperatures. Argon and krypton crystals were grown at temperatures near the triple points of these elements, respectively 84 °K and 116 °K. Studies of the properties and growth characteristics of these crystals were found to be easily correlated with theory.

In cooperation with the George Washington University, a study was made of the properties of coordination polymers formed by combining the ligand *bis*(8-hydroxy-5-quinolyl)methane with divalent manganese, cobalt, nickel, copper, and zinc. Among the many potential applications for such polymers is the fabrication of missile and rocket components. Results of the study show that the decomposition temperatures of the polymers, and hence their thermal stabilities, are directly related to the atomic numbers of the coordinated metals. The findings has led to a better understanding of the mechanism governing polymer decomposition and may be of particular use in predicting the thermal behavior of coordinated systems when only a minimum of experimental data is available.

Continuing research in statistical engineering dealt with applications of probability theory to problems of the reliability of complex systems. A mathematical study was made of the reliability of a system with spare parts, where the spare parts can fail in storage as well as in use. An investigation was begun of mathematical models for the description of changes through time in the probability distributions of characteristics of electronic devices; the dependence of these distributions on age and stress level was considered.

General areas of investigation in operations research included game theory, graph theory, weapon system simulation, Boolean functions (important

in network circuit theory), and mathematical models of distribution networks. A number of mathematical topics relating to the "warehouse problem" (optimal location of a single processing facility) were identified and explored.

Research in mathematical physics continued to be directed toward the application of mathematical techniques to the solution of problems in physics and engineering. Investigations in progress included the determination of bounds on solutions of problems involving elliptic operators, especially those of elasticity; the application of the "stroboscopic" method to the study of nonlinear ordinary differential equations arising from vibration, acoustical, and electrical circuit problems; the interaction of solar corpuscular radiation and the earth's magnetic field; and studies of dynamic phenomena which may affect the operation of plasma propulsion devices.

INTERNAL SUPPORT ACTIVITIES

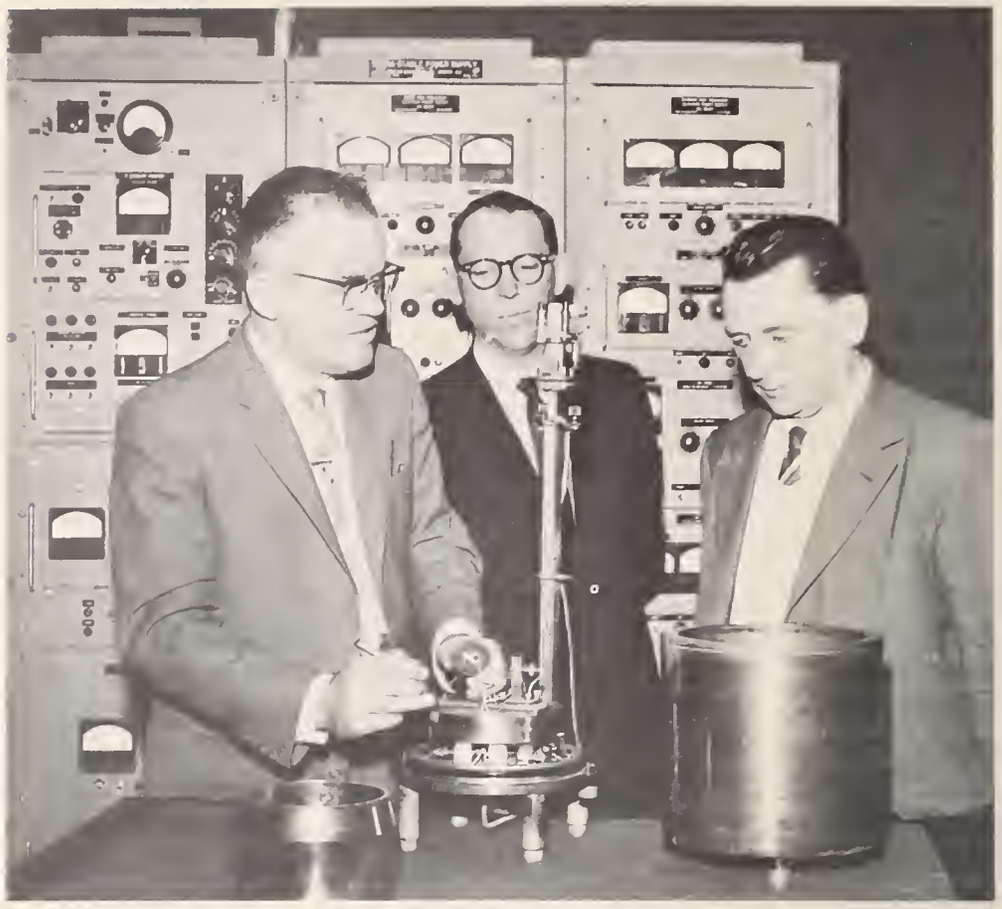
Progress continued in the design and construction of the NBS linear accelerator, Linac, now scheduled for installation at the Bureau's new Gaithersburg (Md.) site in the spring of 1964. This accelerator will produce one of the world's most intense electron beams with energies up to 100 million electron volts, making it possible for the Bureau to enter new areas of nuclear and atomic physics. Tests of the first prototype accelerator section were completed during the year, and a number of investigations were undertaken which allow definition of the ultimate performance of the NBS linear accelerator facility and of other comparable facilities.

A $5 million contract was awarded for construction of a high-flux research reactor and associated laboratories at the Gaithersburg site. This reactor, to be known as the NBSR, will enable the Bureau to fulfill its growing responsibilities in the many rapidly expanding fields of atomic energy. It will be used to advance the measurement, analysis, and understanding of radiation effects on substances of all kinds.

INTERNATIONAL ACTIVITIES

On an international basis, the Bureau represents the interests of the Government and American science in matters dealing with the establishment and maintenance of standards and the establishment of values for scientific constants. Most of this work is done through participation in a large number of international groups such as the General Conference on Weights and Measures, International Union of Pure and Applied Physics, International Union of Pure and Applied Chemistry, International Scientific Radio Union, International Commission on Illumination, and International Organization for Standardization.

The Bureau, in cooperation with the Office of Technical Services, U.S. Department of Commerce, has been actively participating, through the American Standards Association, in the planning and development of pan-American standards for commodities including textiles; iron and steel; cement



Members of the NBS Boulder Laboratories staff explain construction details of the NBS microcalorimeter—the U.S. standard of microwave power—to Dr. Wolfdietrich H. Schaffeld (*right*), Head of the Microwave Physics Laboratory, Physikalisch Technische Bundesanstalt, Braunschweig, Germany. **(See p. 19.)**

and concrete; hides, leather, and tanning materials; and electrical equipment. This program is basic to the economic development of the Latin American countries and to the expansion of trade among these countries and between them and the United States. The Bureau has rendered assistance in the field of weights and measures to several Latin American countries that have requested it, and prototype standards suitable for use as the national standards of developing countries are being procured for demonstration and training purposes.

Another form of international cooperation is the reception of foreign scientists as guest workers or visitors, and the training of foreign specialists in the Bureau's laboratories. During the past year, 662 foreign scientists from 45 countries came to the Bureau as visitors, and 138 trainees and guest workers were received.

The Bureau continued a program initiated the previous year in which funds are granted to scientific laboratories in certain foreign countries in order to support research directly related to the Bureau's mission. In the past two years, 29 grants and contracts totaling more than a million

dollars have been awarded to institutions in India, Israel, and Pakistan. These awards are financed from excess balances of local-currency funds accruing to the United States from the sale of surplus farm products in past years. Recent awards have been for work on imperfections in crystals, dynamics of crystal lattices, nature of the Moessbauer effect, analysis of polymers, vapor pressure of refractories, and reflection of radio waves on ionospheric layers.

In addition to the scientific results of these activities, the program has resulted in an increased interest among foreign scientists in the kinds of problems that are relevant to the Bureau's mission, in greater awareness among Bureau staff members of the scientific potential in other countries, and in intensified communication and exchange of visits.

In June 1963 a seven-man team of measurement specialists from this country, headed by an Associate Director of the Bureau, visited the Soviet Union for a month-long tour of various measurement laboratories. The team consisted of six NBS staff members and one representative of industry. Plans were made for a similar team of Soviet metrologists to visit the United States later in the year. These visits are being conducted under the terms of a United States–U.S.S.R. agreement for the interchange of information and the exchange of visits by teams in 13 fields of technology. The U.S. State Department, under whose general control the exchange program is conducted in this country, requested that the Bureau arrange for the exchange of persons from the area of high-precision measurement standards.

ADMINISTRATIVE ACTIVITIES

During the past year the Bureau initiated a critical examination of its management techniques for determining the needs and priorities of the users of its services and for defining the objectives of its programs to assure the most efficient application of NBS resources. Particular attention has been given to the identification and emphasis of programs that support directly the broad responsibilities of the Department of Commerce for promoting economic growth through science and technology. New techniques are being developed for the formulation, management, and evaluation of NBS programs in terms of certain broad program categories or "mission components" which have been identified.

It has been recognized that the central program of the Bureau is concerned with four related types of standards which are of interest to two broad customer groups. These are (1) basic measurement standards for the physical quantities and units, used by the scientific and engineering community, (2) technological standards such as codes, methods of test, commodity standards, and engineering standards needed by the industrial community to determine the quantity, quality, or performance of technological products and materials of commerce, (3) standard reference data consisting of critically evaluated data on the physical and chemical properties of matter and materials, and (4) standard reference materials for use in controlling industrial processes and maintaining the accuracy of measuring equipment.

The latter two categories of standards are needed by both customer groups.

In examining the total program of the Bureau, certain additional mission components have been identified for management purposes. These include the broad program of background research conducted by the Bureau to maintain contact with impending developments and to provide general scientific competence, extensive consultative and advisory services provided for Government and private organization, and various technical services which supply internal support for NBS activities. In addition, the Bureau operates research and technical service programs in certain "special mission" areas for which the Bureau has a recognized central responsibility within Government. The Bureau's Central Radio Propagation Laboratory, Data Processing Systems Division, and Building Research Division conduct programs of this type.

With the exception of these "special mission" organizations, NBS technical divisions are organized along the classical lines of science and engineering, including divisions concerned with electricity, heat, mechanics, analytical chemistry, atomic physics, etc. It has been necessary, therefore, to devise new management techniques for examining the programs of these subject matter divisions in terms of their contribution to the broader mission components of the Bureau. It is believed that these management innovations will enable the Bureau to be more responsive to the needs of its customers and to achieve better balance in the application of its resources.

To facilitate this new program management plan and to strengthen the Bureau's activities which foster industrial technology, a new position of Deputy Director for Technological Standards and Services was created. This position will have responsibility for NBS programs which contribute directly to the development of commercial and industrial standards and test methods. Included are the commodity standards and international standards programs, which have been conducted by the Office of Technical Services of the Department of Commerce since 1946, and were returned to the Bureau near the end of the year. Assignment of these functions to the Bureau concentrates in the Bureau all of the Department of Commerce programs concerned with the development of industrial standards which provide the common basis for exchange of technological products and services in industry and commerce.

The former Deputy Director has been redesignated Deputy Director for Basic Standards and Services. He will be responsible for NBS programs concerned with the development of basic measurement standards and systems, for the technical services associated with the dissemination of these standards, and for the greatly expanded effort on standard reference data which will result from the recent assignment to the Bureau of responsibility for coordination of a National Standard Reference Data System (see p. 8).

Funds obligated by the Bureau during fiscal year 1963 totaled $59,021,000, including $9,627,000 for facilities. Of the $49,394,000 available for support of the technical program, $28,492,000 came from direct appropriations to

The Engineering Mechanics Laboratory at the new NBS site in Gaithersburg (Md.) is now being occupied by the first working groups to move to their new quarters. (See p. 21.)

the Bureau and $14,584,000 from other Government agencies and private sources. In addition, calibrations, tests, and other reimbursable services amounting to $6,318,000 were performed during the year. A more complete presentation of financial data can be found in appendix 3.3.

The total staff of the Bureau at the end of the fiscal year was 4,160; 2,754 of these staff members were employed in the Bureau's Washington Laboratories, and most of the remainder were attached to the NBS Boulder Laboratories in Boulder, Colo. Additional information on staffing is available in appendix 3.2.

Construction of Phase I of the Bureau's new laboratories near Gaithersburg, Md., was largely completed during the year and substantial progress was made on the remainder of the facility. Phase I, which will be occupied in the near future, includes a boiler plant that will supply heat and cooling for all buildings on the site, and the engineering mechanics laboratory. Erection of the large force-measuring machines that are an important feature of the new mechanics laboratory is in progress, but will not be completed for several months.

Construction of Phase II was started in July 1962 and is well under way. This phase includes four buildings to house the administrative and service activities of the Bureau and the radiation physics laboratory. The latter building will contain the Bureau's new linear accelerator. Construction also was started on the NBS research reactor near the end of the year (see p. 19).

Phase III was started in October 1962 when a contract was awarded for constructing the substructures of the seven general purpose laboratories. This work was nearing completion at the end of the fiscal year and bids had been requested for the remaining construction on these laboratories.

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Phase IV, which includes various special-purpose laboratories, is the last element of the Gaithersburg facility currently planned and the only one not now under construction. Planning for this phase continued during the year. Also in the planning stage is a major new building to house the rapidly expanding activities of the radio standards laboratory at Boulder, Colo.

PUBLICATIONS AND TECHNICAL INFORMATION

To be fully useful, the information developed in the Bureau's work must be communicated to the scientific and industrial community for application in the laboratory and on the production line. Many channels are maintained to facilitate this flow of information.

Probably the main channel is the Bureau's publications program. NBS publications are therefore suggestive of the scope and level of its technical program. During the year these totaled 1,122 formally published papers and documents. In addition, some 420 classified and unclassified reports were issued to other Government agencies.

Among the major publications of the year was Dr. F. B. Silsbee's *Systems of Electrical Units* (NBS Mono. 56). It surveys the various systems of units used in electricity and magnetism and briefly traces their historical development. Dr. Silsbee, one of the world's leading authorities in the field, compares the views of the theoretician and the experimentalist in the derivation of the units.

In his discussion, Dr. Silsbee points out that preferences and philosophies regarding systems of units have changed substantially over the years and are still under discussion by international standardizing bodies. This Monograph is intended as a stimulus to further development, understanding, and utilization of systems of electrical units.

Another major publication was *Tensile and Impact Properties of Selected Materials from 20 to 300 °K* (NBS Mono. 63). The materials referred to are structural materials for use in low-temperature applications—alloys of aluminum, cobalt, copper, iron, nickel, and titanium, and two metal-bonded carbides. Included are tensile strength, yield strength, elongation, and reduction of area values; stress-strain curves; and impact data.

Standard X-ray Diffraction Powder Patterns (NBS Mono. 25, Section 2), the twelfth in a series with this title, also appeared this year. This volume contains 37 standard patterns to aid chemists in identifying unknown crystalline materials by X-ray diffraction. *Radiobiological Dosimetry: Recommendations of the International Commission on Radiological Units and Measurement* (NBS Handb. 88) is in effect a handbook for the radiobiologist and considers methods for improving accuracy and comparability of absorbed dose measurements.

Of the 1,122 formal publications issued during the year, 180 were published in the *Journal of Research*, and 736 in the journals of professional and scientific societies. Also, 132 summary articles were presented in the Bureau's monthly *Technical News Bulletin*. In the nonperiodical series of

publications, 74 papers were published: 18 in the Monograph series; 4 in the Handbook series; 3 in the Miscellaneous Publication series; and 49 in the Technical Note series.

Central Radio Propagation Laboratory Ionospheric Predictions, the Bureau's third periodical, which is published for a one-month period three months in advance, presented radio propagation data needed for determining the best radiofrequencies to use in long-range radio communications. A fundamental change in form and content was made in the *Predictions* beginning with the January 1963 issue. The predictions are now prepared by a method of numerical mapping using a high-speed electronic computer. The new format includes tables of coefficients which, when used as input data with a suitable program, make possible the use of a computer for calculation of detailed high-frequency radio propagation predictions for any application. World prediction maps for every even hour, Universal Time, are provided for subscribers without access to computer.

A list of publications for the fiscal year, which includes several papers published in the previous year but not reported, is given in the appendix, section 3.7 (p. 212).

Secretary of Commerce Luther H. Hodges (*right foreground*), Assistant Secretary of Commerce for Science and Technology J. Herbert Hollomon (*speaking*), and NBS Director A. V. Astin (*center*) at a preview of the NBS Open House commemorating the Commerce Department's 60th Anniversary. The special preview was held for Government officials, Congressional staff, and members of the press. **(See p. 24.)**

Scatter Radar: Space Research from the Ground, a 23-minute, 16mm color movie, was released during the year. The picture tells the story of the Jicamarca Observatory, new NBS facility near Lima, Peru. Jicamarca, largest installation of its kind in the world, utilizes a 22-acre radar antenna. It probes the upper atmosphere to measure electron densities, has already made observations of the planet Venus, and will study the solar corona and solar gases.

On May 11, 1963, the NBS Washington laboratories were opened to the public for the first time in many years. The open house program was a part of the celebration of the 60th anniversary of the Department of Commerce. Approximately 7,000 persons visited during the day and went on selected tours among the more than 100 laboratories and special exhibits that were open for public inspection. At the NBS Boulder, Colo., laboratories, the anniversary was also commemorated by special tours and open houses for high-school students and the general public.

During the year, the Bureau participated in 18 scientific and technological exhibitions, with exhibits depicting the Bureau's research programs. Featured in several of these exhibits was a working model of the NBS ultrasonic thermometer, operating at liquid helium temperatures. Typical of the year's shows were National Academy of Sciences, Washington, D.C.; International Symposium on Humidity and Moisture, Washington, D.C.; Northeast Commerce and Industry Exposition, Boston, Mass.; National Electronics Conference, Chicago, Ill.; and National Scale Men's Technical Conference and Exhibit, Cleveland, Ohio.

The Bureau's motion picture program included 3,694 showings of NBS films to a total audience of 434,359, including educational television.

2. HIGHLIGHTS OF THE RESEARCH PROGRAM

The Bureau's technical program is carried out through organizational units called divisions. These are shown in appendix 3.1 in numerical order. A review of selected research and development programs is presented in this section under headings corresponding generally to these organization units but rearranged to bring together related types of activity.

2.1. PHYSICS, ELECTRONICS, AND MEASUREMENT STANDARDS

2.1.1. METROLOGY

The metrology laboratories of the Bureau provide a central basis for a system of physical measurement by maintaining, developing, and disseminating standards for commonly used physical quantities such as length, mass,

volume, density, and angle, as well as for light, color, electromagnetic radiation, and other optical and photographic quantities.

With the assistance of the Advanced Research Projects Agency, work on the thermal and optical properties of materials was expanded during the year to include measurements of the optical properties of infrared-transmitting materials. Research is in progress on the measurement of the transmissivity, reflectivity, emissivity, homogeneity, and scattering properties of materials widely used in space, industrial, and research applications.

The calibration program has been strengthened by the use of automatic measuring and computing equipment, particularly in the calibration of mass standards. The resulting savings in human labor formerly required permitted the Bureau to offer new calibration services with less delay and to devote more effort to the development of improved measuring systems and standards.

A New Standard of Spectral Irradiance. The accurate measurement of spectral irradiance has assumed increasing importance in connection with studies of the irradiance to which space vehicles will be subjected. The making of such measurements was facilitated by the development of a new standard of spectral irradiance, a 200-watt quartz-iodine lamp with a coiled-coil tungsten filament operating at about 3000 °K. The lamp is obtained from a commercial source and is calibrated in microwatts per square centimeter of receiver per nanometer of waveband pass over the spectral range of 0.25 to 2.6 microns (μ). Unlike the standards of electrical radiance which have been available for several years, the lamp is used without auxiliary optics and, because of its small physical size and high operating temperature, it provides relatively high spectral irradiances.

Basis for Color Measurement Amended. Since 1931 the international basis for color measurement has been the color-matching functions for the average normal eye as derived statistically from measurements made by a large number of observers. These functions were obtained from observations made of visual fields subtending 2 degrees at the eye and they give satisfactory predictions for field sizes between 1 and 4 degrees. However, industrial inspections of many products such as paints, papers, plastics, ceramics, and textiles are customarily made by checking a large specimen (that is, a visual field subtending 10 degrees or more) against an equally large color standard, because smaller color differences are detectable this way. But the color matches thus set up often fail to hold for the same samples viewed at a distance. This apparent discrepancy results from the fact that the central part of the normal eye is covered by a spot of yellowish pigment.

In 1957 the International Commission on Illumination requested the Bureau to derive a set of color-matching functions for the 10-degree field from observations of such fields made by a number of observers at the National Physical Laboratory in Teddington, England, and at the State Optical Institute in Leningrad, Russia. The derivation was completed in 1959 and the resulting functions were subjected to intensive practical trials in Canada,

Great Britain, Russia, and Spain, as well as in this country. At the 1963 meeting of the Committee of Experts on Colorimetry of the International Commission on Illumination in Vienna, Austria, these functions were recommended for use in color measurement as a supplement to the 1931 functions.

Calibration of Flashtubes. The use of flashtubes (strobelights) is becoming increasingly important for both terrestrial and extraterrestrial signalling purposes; hence, evaluation of the flux produced by a flashtube in terms of its effect on the human eye is required. Accordingly, the Bureau recently undertook the calibration of flashtubes, reporting either the candle-seconds per flash in a specified direction or the lumen-seconds per flash, as required. Both the flashtube and its associated power supply are submitted for calibration, together with a triggering mechanism which triggers the flashtube repetitively at a stable rate of about one or two flashes per second.

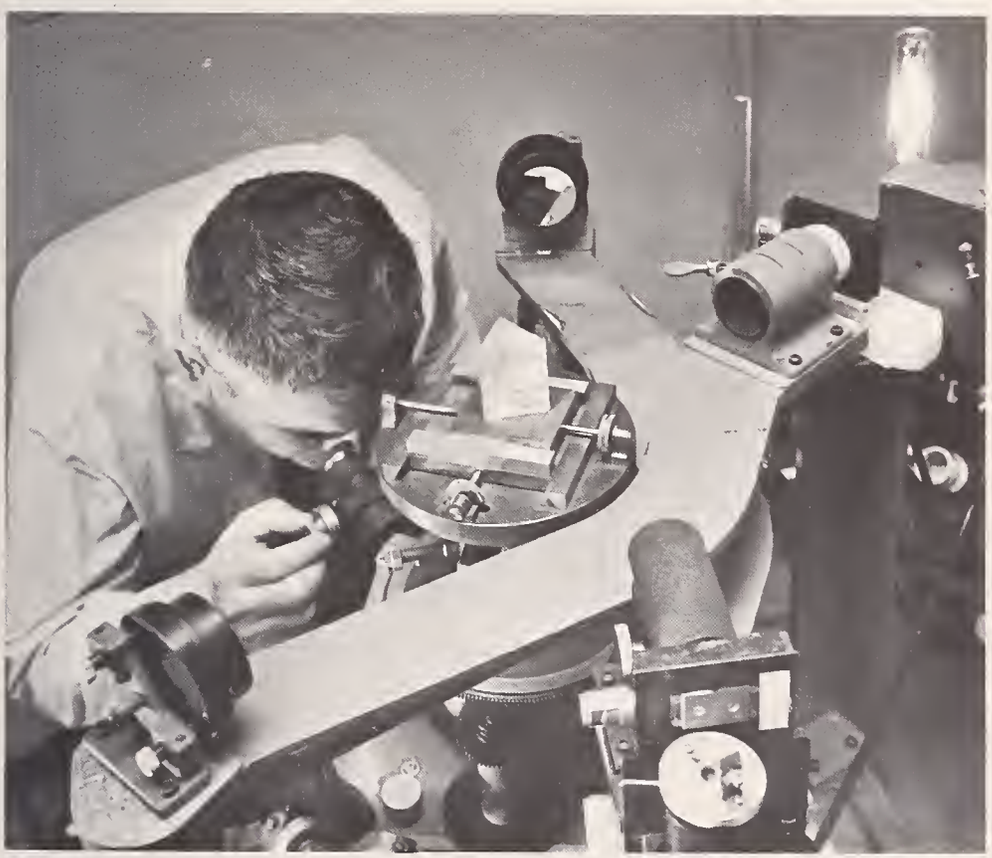
Fluorescent Lamp Measurements Intercompared. The Bureau recently participated in the first international intercomparison of photometric and colorimetric measurements on fluorescent lamps with the national laboratories of seven other countries. Three 40-watt fluorescent lamps of each of three different colors were supplied by the British National Physical Laboratory to the participating laboratories. Laboratory measurements made of total light output (luminous flux) covered a spread of about 4 percent, with the individual results varying from -2.4 to $+1.5$ percent from the world mean. The NBS value was -0.8 percent from the mean. Although the variance in the results was not deemed exorbitant, the International Commission on Illumination requested the International Bureau of Weights and Measures to take steps to narrow the spread.

Color measurement results were more divergent and seemed to depend on whether visual matching or spectroradiometry was used. The Bureau values obtained by means of a colorimeter (calibrated with fluorescent lamps that had been calibrated visually by incandescent lamps and colored filters) were in good agreement with the world mean. However, Bureau chromaticity results derived from spectroradiometric data were in poorer agreement. Spectroradiometric results obtained by U.S. lamp manufacturers were compared and were also found to contain substantial differences. Consequently, since the international goal is to place the colorimetry of fluorescent lamps on an objective basis that is dependent upon spectroradiometric data, an investigation of the whole problem of data reproducibility is being undertaken.

Equipment Developed for Calibrating Thermal Detectors. A new standard "blackbody" detector and a filter spectroradiometer for use in the calibration of thermal detectors were developed. The detector consists of an inside-blackened gold-foil conical receiver to which is attached a series of thermocouples. It has a spectral emissivity of 0.99 or more throughout the spectrum from the short ultraviolet to the long infrared. The filter spectroradiometer consists of narrow-band interference and other glass filters, and mercury line sources, tungsten lamps, and globar radiators.

During a calibration, the sources with the filters produce spectrally homogeneous lines and narrow bands at some twenty wavelengths between 0.25 and 20 μ to successively irradiate uniformly over their entire surfaces the new standard detector and the detector under test. The relative spectral response of the test detector is thus measured as the ratio of the two responses as a function of wavelength. All commercial thermal detectors measured so far vary in response with wavelength by 5 percent or more. However, their calibration permits their use in precise radiometric investigations.

Equipment Developed for Densitometric Calibrations. A quantitative method of photometric attenuation was developed for densitometric calibrations. A rectangular aperture fitted with a sliding straight-edged shutter is employed. Light flux through the aperture is made proportional to the open aperture area by a compensating procedure, as follows: When a thin slit is moved across the aperture, the light passing through the slit to a detector is compared to the light coming from the same source by a different path. If the response of the detector is constant as the slit moves, the shutter is replaced, and the flux through the aperture to the detector is then known to be proportional to shutter displacement, which can be measured precisely. If detector response is not constant, the aperture edges may be shaped or an optical compensator may be placed in the aperture to produce



Measuring the refractive indices of synthetic calcium fluoride. Such values provide a basis for selecting optimum crystalline materials for the design of optical components and systems. **(See p. 30.)**

the required condition. Two slits may be used to establish an exponential or inverse square relationship to the shutter displacement if desired. The method requires about one-tenth the space required by the inverse-square method now in use, and it is less subject to certain errors. Its applicability to the calibration of photographic-density step tablets was confirmed experimentally and the equipment is being refined.

Refractive Index of Calcium Fluoride. The increasing use of calcium fluoride for infrared and ultraviolet optical devices, particularly in military detection and guidance systems, suggested the use of synthetic calcium fluoride—which has been available for several years—for such applications. However, the refractive index of the synthetic material, which must be carefully considered in the design of such devices, was known for only the visible region of the spectrum. The Bureau therefore measured the refractive index of both a synthetic and a natural crystal of calcium fluoride over a wavelength range from 0.23 μ in the ultraviolet to 9.7 μ in the infrared. Results indicate that synthetic crystals, when properly prepared, are comparable in refractive properties to natural crystals.

Generalized Lens-Bending Procedure Developed. A tool often used by the optical designer is the well-known procedure of bending a lens element; that is, varying the curvatures of both of its refracting surfaces by some common increment. The increment is an independent variable, while the two curvatures of the lens system represent parameters dependent on it for their modified values. A family of lens elements is thus defined, each member of which possesses useful properties in common with the original lens element. When this element is a thin lens for which the refractive indices are the same on both sides, the paths of the marginal and principal paraxial rays are left invariant over the remainder of the lens system.

A generalized lens-bending procedure recently developed for the case of thick lenses and unrestricted refractive indices possesses this same invariance property with respect to the path of the two paraxial rays. The procedure required variation (by unequal amounts) of the curvatures of the usual two surfaces, together with related variations of two vertex separations. Indices of refraction are not modified. Thus, variation of four lens parameters is obtained as a function of the independent variable which specifies the amount of "bending" desired. The chief advantage of generalized bending is that it allows variation of third-order aberrations arising from a single element of a lens system, independently of the remainder of the system.

Technique for Deriving Principal Curvatures of Wave Fronts. A mathematical technique was recently developed for determining the principal curvatures of a refracted or reflected wave front in an optical system. The technique extends geometrical analysis beyond traditional ray tracing for a large class of optical systems. Since the amplitude of the electromagnetic wave associated with the wave front is inversely proportional to its Gaussian curvature, the technique is useful in any attempt to describe quantitatively the physics of light propagation in lenses.

Images, photographed at various focal planes on the lens axis, formed by placing a perforated plate on the front surface of a long focal length lens and illuminating it with collimated light. These "spot diagrams" aid in the determination of the geometrical properties of the lens. (A) taken on the lens side of the position of best focus; (B) taken at the position of best focus; (C) taken beyond the position of best focus. **(See p. 30.)**

An immediate application was found for the results of this work in a study of designs for grating spectrometers. Long-range applications are anticipated in the area of physical optics. A computer program was prepared to obtain automatically processed data for required calculations.

Image Evaluation. In an image evaluation program on photographic objectives, work is in progress on the effects of known defects (such as striae, bubbles, feathers, streaks, and surface scratches) in objective lenses on limit of resolution, wave front shape, frequency response, and general picture quality. Five lens samples are being observed, supposedly differing only in the glass from which they were made. A lens of good glass quality is included in the group as a control.

Measurement of Wave Fronts. A method was developed which permits the measurement of the departure of the wave front emergent from a lens from a true spherical wave front in terms of wavelength. The method involves the measurement of the displacements of the central fringe of an interference pattern. The pattern is produced by the introduction of a double slit into the beam of light incident upon the lens. Measurable displacements of the pattern occur as the double slit moves across the front of the lens. An accuracy of ± 0.02 wavelenth is attained.

Stored Microfilms Inspected. As part of a study of the permanence of photographic materials, large numbers of microfilms of Government records were inspected. The inspections revealed a rather widespread incidence of microscopic defects after 2 to 20 years of storage. These defects, confined almost exclusively to negative microfilm, are circular reddish spots from 15 to 150 μ in diameter, some having a concentric ring structure, or a decrease in density and general broadening of printed lines and other information. Practically no information loss was observed, but the necessity of periodic inspections was made clear.

Microcopy Chart Designed. In response to demands of science and industry, a microcopy resolution test chart was designed. When proposed minor amendments are made in existing microcopying specifications, the new chart will replace the current NBS Standard Sample No. 1010. Chart

color, line type, contrast, line-to-space ratio, number of lines per group, and length-to-width ratio of lines conform to current specifications. Very small changes were made in a few spatial frequencies to make the series conform to an international standard preferred-number series. A slight alteration in the layout of the patterns permits the frequency range to be extended to higher or lower frequencies and permits the chart to be abridged conveniently when desired. A small change in the size of the sheet will have no effect upon the usefulness of the chart but will accomplish considerable economies in time and materials in chart production.

Method Developed for Measuring Thiosulfate in Processed Film. A new analytical procedure for measuring the thiosulfate radical remaining in photographic film after processing was developed. Such measurements are routinely done at the Bureau to ascertain conformance to microfilming specifications which require that films be sufficiently well washed to reduce thiosulfate concentration to less than 0.005 mg per square inch (reported as sodium thiosulfate). The current standard analytical method has been in use for the past 30 years. The new procedure, which is based on the same chemical principles, reveals two to three times as much residual thiosulfate as does the current standard procedure. A new method of measuring the residual non-image silver in processed film was also developed.

Length Measurement Research. Ultra-precise methods for making length measurements are being sought so that length standards may be calibrated to an accuracy approaching a tenth of a microinch. Toward this end, an ellipsometer was acquired to determine the thickness of the thin film existing between joined gage blocks. In application, these films are an inherent part of the length of end standards of length. To aid in this research, a theory was developed on the behavior of light beyond a surface normally thought to be totally reflective.

Thermal Expansion Measurement Capability Extended. Additional data are needed on the thermal expansion of materials in the extreme environmental conditions of outer space and in the thrust nozzles and heat shields of space vehicles. So equipment designed to increase Bureau measurement capability from 1000 to 1700 °C was installed and operated thus far at temperatures above 1600 °C. Cryogenic equipment was also designed and is now under construction. This equipment will extend the Bureau's minimum temperature range capability to −250 °C.

Wave-Front-Shearing Interferometer. A wave-front-shearing interferometer was developed and applied to the testing of mirrors and lenses. In one study, it was placed at the focus of a 26-in. refractor at the University of Virginia, in probably the first interferometer test of an astronomical telescopic *in situ*. Four photographs of interference fringes were obtained by changing the direction of shear 90° between each photographic operation. The shape of the wave front as it emerged from the objective could then be computed. By way of further development, a means was devised for rotating the fringes into the direction which would provide the best accuracy.

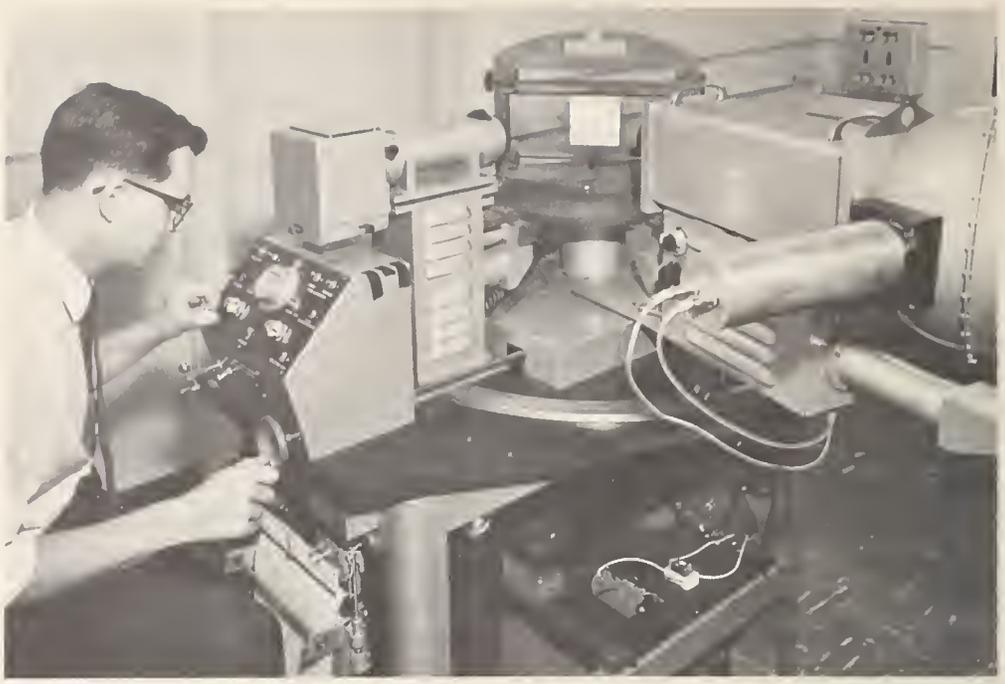
Screw Thread Standardization. Thorough consideration was given by the American Standards Association's Sectional Committee B1, the Interdepartmental Screw Thread Committee, and a recent American-British-Canadian Conference on Engineering Standards to the revision of the definitions of pitch, groove, ridge, and functional diameters of screw threads. The revisions were correlated with types of limit gages and measuring methods to clarify a dimensional control problem. The new concepts developed will be published in revisions of *Nomenclature, Definitions, and Letter Symbols* (Section II of NBS Handbook H28), and American Standard B1.7.

In other studies, a critical review was made of the factors which affect the accuracy of pitch (or groove) diameter measurements by the use of thread wires, and proposed revisions in standard measuring practice were developed. The revisions will provide optimum compensation of elastic deformations under measuring forces and will prevent excessive compressive stresses which would cause permanent deformations.

Laser Produces Fringes Over 200-Meter Path. Improvements in the design of a helium-neon laser permitted its output to be operated at a single mode (the highly monochromatic portion of a single spectrum line). It was found that a quartz spacer tube maintained constant spacing of the instrument's end reflecting plates and thus the stability of laser frequency. In recent work with the laser, its infrared light of wavelength 11,530 Å applied to a modified Michelson-type interferometer produced fringes that were first converted to visible wavelengths and then observed and photographed over a 200-meter optical path.

Cockpit Lighting in TFX Aircraft. Advisory services, provided by the Bureau to Navy, Air Force, and General Dynamics Corporation engineering personnel, led to standardization of the color of illumination for the cockpit lighting of TFX (F–111) aircraft, and to the first specified use of electroluminescent sources for cockpit lighting in an American plane. The standardization will result in monetary savings in the production of this plane.

Accuracy of Spectral Transmittance Standards Investigated. For a number of years the Bureau has been issuing glass filters (selenium red, carbon yellow, copper green, and cobalt blue) for use as spectral transmittance standards in checking the photometric scale of spectrophotometers throughout the visible spectrum. The NBS reference standards used to calibrate these filters are periodically evaluated at the Bureau to determine their true spectral transmittance values. However, the results of two recent recalibrations of a set of the issued filters suggested a possible drift in the spectral transmittance values of the NBS standards. An extensive recalibration was therefore undertaken of the latter. The measurements obtained showed that the values of spectral transmittance at some wavelengths differed slightly from previously assigned values but not by amounts exceeding the combined uncertainties of former calibrations and the present recalibration.



Measurement of reflective properties of materials used for balloon satellites. The measurements will provide a basis for analysis of the effect of radiation pressure on such satellites. (See p. 34.)

Goniophotometry. To assist the National Aeronautics and Space Administration with an analysis of the effect of radiation pressure on a balloon satellite, goniophotometric measurements were made on plane specimens of the skin at a large number of angles of incidence and viewing. The results were reported in terms of the intensity factor, that is, the ratio of radiant intensity to incident flux. The data were obtained with a manual point-by-point goniophotometer. Subsequently, the Bureau received delivery of a custom-built recording monoplane goniophotometer. The new instrument will greatly facilitate goniophotometric investigations of reflected and transmitted flux distributions from all kinds of materials.

2.1.2. MECHANICS

The Bureau's work in mechanics is primarily concerned with the development and improvement of measurement methods for mechanical phenomena in solids, liquids, and gases; the establishment of required standards in mechanics and the relation of such standards to prototype standards; the support of these activities by theoretical and experimental research on mechanical phenomena; the determination of physical constants of particular importance in mechanics; and provision of assistance to other laboratories in relating their measurements to a common basis (or to established standards) by transfer standards, calibration services, and other means. Measurement areas include sound pressure and intensity, shock, vibration, force, strain, pressure, vacuum, viscosity, and rate of gas and liquid flow.

These measurement areas are of importance to scientific and engineering programs (including those of the space effort) which require great accuracies over wide ranges under extreme temperature environments. Special emphasis is therefore given to research directed toward meeting these needs.

The design of special-purpose equipment to be installed in the Engineering Mechanics Laboratory at Gaithersburg, Md., was completed. This equipment includes deadweight testing machines of 113,000-lb, 300,000-lb, and 1,000,000-lb capacity and a universal testing machine of 12,000,000-lb capacity. Design work progressed on two other laboratories, one for sound experiments and the other for fluid mechanics research. When these three facilities are in operation, it will be possible to provide improved services in several of the measurement areas in mechanics.

Vibration Amplitudes Measured. The range of amplitudes over which vibration-measuring instruments can be calibrated photometrically with a Fizeau optical interferometer was extended by the development of a method to replace the human observer method previously used. The new method covers amplitudes from 1090 angstroms (Å) up to about 1 micron (about 4 to 40 microinches) and the entire range of audiofrequencies up to 20,000 cycles per second (c/s), in contrast to the amplitude range of the old method of from 72 to 4400 Å.

A unique feature of the new method is the vibration of *both* plates of the interferometer, one at a modulating frequency much lower than the calibrating frequency of the other. The resulting modulated light flux is detected by a photomultiplier. The photomultiplier signal is analyzed electronically so that a meter shows a sharp null when the amplitude of vibration of the plate, moving with the vibration pickup attached to it, reaches one of a number of accurately known values determined by the optical wavelength. This method improves the precision of Bureau calibrations and reduces the time required to perform them.

Microphone Calibration. Pressure calibrations of condenser microphones are usually carried out in small hydrogen-filled couplers at ambient barometric pressure. During the past year, an apparatus was developed which prevents excessive loss of hydrogen from the coupler for long periods of time. This apparatus connects the coupler's capillary tubes to relatively large containers of hydrogen and vents the containers to the atmosphere through additional capillary tubes. The system provides ample time for performing reciprocity calibrations accurately in the three cubic centimeter couplers that are used over a frequency range from 500 to 20,000 c/s.

Portable Tube Designed for Sound-Absorption Measurements. A portable acoustical impedance tube was developed as an instrument for practical research on sound-absorbent materials. The tube makes precision measurements of impedance and sound absorption in both laboratory and field installations, over the frequency range from 400 to 900 c/s. It is useful for the development, manufacturing control, and acceptance testing of acoustical materials installed in various buildings, as well as for the determination of aging, staining, and redecoration effects on sound absorption.

Cavitation Data Obtained. Cavitation, or the opening up of cavities in liquids subjected to tension, has been intensively studied for years. *Hydraulic cavitation*, such as that occurring on and about ship propellers, is of great practical importance since it wastes power and damages propeller blades. Another type is *sonic* cavitation, in which tension occurs during the rarefaction phase of an intense sound wave. This effect is commercially important in sonic processing.

A fundamental problem in sonic cavitation is the origin of the nuclei, which are very small air-filled or vapor-filled cavities. Theory indicates that they must preexist in order for catastrophic expansion to take place at the levels of tension (cavitation threshold) observed. Workers abroad report evidence that nucleation is primarily induced by secondary neutrons connected with cosmic radiation. Independent experiments along these lines are under way at the Bureau, jointly sponsored by the Office of Naval Research.

Cavitation thresholds are notoriously irregular, and quantities of data are needed on these thresholds for statistical processing; however, an inordinate amount of labor is involved. So in the current Bureau study, a device which automatically measures and records the cavitation threshold of a sample of water 100 times a day was developed. After automatic processing of these data by an electronic computer, it may be possible to separate the effects of the numerous variables involved and thus obtain additional evidence on the nucleation process.

Measurement of Impact Sound Transmission in Buildings. A comprehensive study was undertaken during the year to develop a standard test method for the measurement of impact sound transmission. In this study, in which three other laboratories participated, a roundrobin series of impact tests with a standard tapping machine was conducted on basic 4-in.-thick concrete floor specimens. The specimens were subsequently surfaced with acoustical materials and again tested. Field measurements on floor structures nominally identical to those measured in the interlaboratory program are currently in progress to determine the correlation that exists between laboratory and field measurements.

This study, jointly sponsored by the Army, Navy, and Air Force, was closely coordinated with work of the Federal Housing Administration, which recently developed the first impact-noise criteria for use in this country. The criteria, based in part on NBS laboratory measurements, were recently published as FHA Report No. 750, "Impact Noise Control in Multi-Family Dwellings." This document is a clear and concise guide for the control of impact noise, and it is designed for use by the FHA insurance staff as well as by architects and builders.

Infrasonic Waves Studied in the Atmosphere and in the Earth. Preliminary comparisons of sound waves received at the Bureau's new infrasonics station in Boulder, Colo., and at the station in Washington, D.C., reveal a number of time intervals in which signals were recorded from the same source in a distant geographical area. Comparisons of arrival directions at the two stations now being made will allow some fairly precise deter-

Measurement of impact noise produced on floors by footfalls. The sound is transmitted through the floor and measured in the room below. Results produced in this way are being compared with measurements of noise from the standard tapping machine usually used in laboratory work. Sound measurement is an important step in the formulation of sound insulation requirements in building codes. (See p. 36.)

minations of the geographical areas from which signals are generated by ionospheric disturbances, tornadic storms, volcanoes, and by presently unknown sources.

Observations with a temporary infrasonics station at Fort Yukon, Alaska, confirmed that infrasonic waves, previously associated with geomagnetic activity from measurements at the Washington, D.C., station, were caused by auroral disturbances. Comparison with geomagnetic fluctuations and cosmic radio noise absorption effects indicated an atmospheric pressure wave source intimately connected with the behavior of the auroral ionosphere. The temporal and geographical distribution of the ionospheric disturbances are controlled by the position of the sun and the level of solar activity.

Further observations on infrasonic waves (having periods of about 6 seconds), commonly called microbaroms, confirm the hypothesis of their oceanic source. The ocean waves periodically arriving on the eastern seaboard can radiate enough sound to cause microbaroms to be observed at Washington. They are present also at Boulder, but substantially weaker because of the greater distance from the coasts of North America.

Infrasonic waves radiated by tornadoes in the midwest continue to be received at the Washington station. They are also observed at the Boulder station and at the Boston station of the Air Force Cambridge Research Laboratories. Such waves have periods longer than 10 seconds. (Other aspects of this study are discussed in 2.3.4, Geomagnetic Micropulsations and Infrasonic Pressure Waves, page 146.)

Three seismometers of a type developed at the Bureau were installed at sites several kilometers apart in the Washington area. A telemetry system has been worked out so that seismic vibrations are simultaneously recorded at the Bureau. The seismometer system is now being used to determine the speed and direction of microseisms, having periods near 6 seconds, propagated through the Washington area. The possibility of a common origin for both microbaroms and microseisms is being investigated.

Audiometry Research. People usually hear by sound waves which travel down the ear canal to the eardrum (air conduction), but sounds can also be heard when a vibrator is applied to the bones of the head (bone conduction). The least sound that can be heard is called the threshold, and a knowledge of its level is important in the medical diagnosis of impaired hearing. Also of importance are the relative levels of the air-conduction and bone-conduction thresholds.

Air-conduction thresholds measured on 12 young otologically normal persons were used to determine the maximal displacement amplitudes of the basilar membrane in the inner ear. Bone-conduction thresholds in terms of vibratory displacement of the skull, measured on the same group, were related to the displacements of the basilar membrane. These data were then used to determine vibratory motion transmission characteristics for the mastoid and forehead bones. Data obtained on the mechanical impedances of the head bones for the same persons were combined with the threshold displacements to obtain basic information on the vibratory power required for hearing by bone conduction.

Data on the threshold of hearing by air conduction are best stored as sound pressures produced at various frequencies by an earphone placed on a coupler. The coupler contains a small volume of air and a microphone for measurement of the sound. Such a coupler was developed years ago at the Bureau as a standard for audiometric measurement. The technical committee on electroacoustics of the International Electrotechnical Commission recently decided that this coupler was suitable for storage of threshold data newly adoped by the International Standards Organization. The committee will therefore issue a report describing the coupler to facilitate international use of standard thresholds in audiometry.

Improvements Sought in Pressure and Vacuum Measurements. The range of pressures (from 10^{-15} millimeters of mercury to 50,000,000 psi) of interest in science and industry is so vast that many different types of instruments and techniques are required. Efforts are being made at the Bureau to extend pressure-measurement capability by improvements in the design and construction of apparatus, and to develop better experimental techniques.

In the range of high-pressure measurement, the freezing pressure of mercury at 0 °C was determined to be 109,722 psi with an accuracy of ± 30 psi. This pressure fixed point is adequate as a calibration point to serve current needs. The mercury experiment verified the advantage of a manganin resistance pressure gage as a working pressure gage. The full potential of manganin gages has not been realized, so the electrical system for pressure

measurements is being improved in order that more detailed study may be made of the pressure-temperature-resistance characteristics of manganin.

A new piston gage is under construction for use in a more accurate determination of the phase transition of bismuth between 365,000 and 370,000 psi. This transition has served as the principal calibration point for the ultra-high-pressure range. Work has continued on the "two-stage" modification of a tetrahedral apparatus in which stishovite, a form of quartz, has been produced at a pressure of 2,000,000 psi and a temperature above 3000 °F.

Studies in vacuum measurement were continued in the search for force-per-unit-area techniques as contrasted to the indirect methods usually employed in the field. Such techniques are needed to increase the accuracy of conventional vacuum measurements. A detailed study of capillarity effects on the widely used McLeod gage is being carried out. Volume expansion of a fixed quantity of gas was used to study McLeod and ion gage characteristics. Preliminary experiments on an interferometer—oil-manometer led to the design of an improved model which is now nearing completion.

Computer Techniques Applied in Turbulence Studies. In collaboration with the David Taylor Model Basin, a digital computer technique is being applied to the measurement of the statistical properties of turbulence. Thus far, probability distribution, time, space, and space-time correlations in an isotropic turbulence field have been measured. The results demonstrate the feasibility of applying such methods to the measurement of turbulence and provide extensive information as to the space-time transformation and higher order correlations.

Correlation measurements up to the eighth order were obtained by the computer technique, representing a significant step beyond the fourth-order correlations previously derived by conventional analog methods. The computer application to the measurement of other pertinent quantities such as derivatives, higher orders thereof, and joint probability distributions will be investigated.

Boundary Layer Instability and Effect of Roughness. Due to the instability of fluid laminar flow in a thin layer near a wall, known as the boundary layer, ensuing turbulent motions completely alter the characteristics of the flow. It is known that instability gives rise to selective amplification of initially small disturbances and that the end result of the process is a breakdown of the flow to the turbulent state. In a program sponsored by the National Aeronautics and Space Administration, the manner in which turbulent motions begin as the result of an instability has been under investigation for some time.

In the investigation, the breakdown process was traced by means of sensitive hot-wire probes through its various stages. This technique revealed that before the motions become turbulent and while they are still wavelike in character they become three-dimensional. In doing so, they modify the flow at certain localities along the wave train and give rise to a second type of instability—the so-called inflectional instability—from which final breakdown ensues.

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When a wall is not smooth, the roughness elements usually cause or promote transition to turbulent flow. While empirical rules for this effect have been established, the mechanism involved has in general remained obscure. The present study has, however, revealed the mechanism involved when the roughness is a single, two-dimensional element commonly called a trip wire. Systematic measurements showed that this type of roughness element promotes transition by destabilizing a region of modified flow downstream from the element. In this more unstable flow field, selective amplification of ambient disturbances is increased. The observed amplifications are in line with existing stability theory.

Standards Designed for Million-Pound Forces. As a part of a program to support the Nation's efforts in space, the Bureau is constructing a series of deadweight force machines in ranges up to one million pounds at its new laboratories now being built near Gaithersburg, Md. The continued accuracy of these machines is being assured by the acquisition of a set of three reference standards of mass made of stainless steel in units of 10,000, 20,000, and 30,000 pounds. These weights, the largest ever constructed to meet Bureau requirements, have been adjusted to an accuracy of one-thou-

Ten-, twenty-, and thirty-thousand pound mass standards compared to a one-kilogram mass. These weights, the largest ever constructed to meet NBS Class C requirements, will be used in the deadweight force machines now under construction at the new Gaithersburg laboratories. **(See p. 40.)**

sandth of one percent. A precision scale, having a capacity of 30 tons and sensitive to a variation of 2 ounces, will permit comparison of the working weights of the deadweight machines against the reference standards.

Compact Precision Centrifuge Constructed. A centrifuge with a 36-in.-diameter table was designed and constructed to calibrate precision accelerometers over an acceleration range from 1 to 80 *g* with errors that do not exceed 0.1 percent. For calibration of servoaccelerometers, accurate knowledge of the location of the seismic mass is important. This location may be determined by indirect means as a function of the output signal.

Rheological Constitutive Equations. A special constitutive equation has been found adequate to explain stress relaxation data for a variety of polymeric materials in simple uniaxial extension over a wide range of extension ratios. Discrepancies appear, however, when this equation is applied to equilibrium data on biaxial extensions. In an effort to develop a more comprehensive expression which will account for the biaxial measurements as well as for the uniaxial ones, a new theory of incompressible elastic materials was developed. This theory is more general than the usual ones in that it allows an isotropic pressure to affect the shear. Experiments on simple extension of rubber strips under varying isotropic pressure indicate that the new theory is indeed germane. Further studies are in progress to determine whether it will eliminate discrepancies in biaxial data.

In a related study, a test was made of a conjecture originally advanced by Weissenberg on the equality of certain normal stress components in elastic fluids. This was a qualitative test to see if direct evidence could be found by a search for streaming in cross-sectional planes in a fluid flowing through a pipe of rectangular cross section. The observations showed that the flow through certain regions of the pipe followed a spiral rather than a straight line. This evidence indicates that the Weissenberg conjecture does not hold, a conclusion also reached by Markovitz at Mellon Institute recently on the basis of certain quantitative measurements of normal stress.

Review of Volume Relaxations in Polymers. A survey of experimental data on volume (dilatational) relaxations in amorphous polymers was completed. The survey was concerned with the time scale or frequency of measurement as related to temperature and static pressure. For natural rubber and poly(vinyl acetate) there are reasonably complete measurements, principally those made at the Bureau of the dynamic bulk modulus. For other polymers the data are incomplete and often fragmentary. From the data available, however, certain generalizations may be made with a reasonable degree of confidence.

Dilatational relaxations are apparently found in all amorphous polymeric systems. The effects of temperature and pressure are qualitatively the same on the relaxation times associated with dilatation as they are on those associated with shearing motions. In some cases these effects are not only similar but are quantitatively identical, indicating in these cases that the same molecular motions excited by a shearing force are excited by a pressure.

The data suggest that this identity holds in cases where the molecular motions involved are solely cooperative motions of segments of the main chain. The maximum number of segments participating in cooperative motions in response to a pressure is very much smaller than the maximum number involved in response to a shear force. This conclusion is supported by the fact that the relaxation spectrum for dilatation extends over a smaller range of time than does the relaxation spectrum for shear.

Hypersonic Combustion. Research was continued on the properties of detonation waves stabilized on a hypervelocity missile in a stationary combustible gas. Wave structure in hydrogen and air was derived on the basis that a bimolecular reaction controls the rate of heat release behind the shock front. Effect of heat release in the flow field on wave shape and position was derived by a graphical and numerical integration of the equations of motion of the gas between the wave front and missile. The reaction rate constant was adjusted to yield equality of computed and observed wave shape and position over a range of pressures and Mach numbers. Thickness of the detonation wave was derived to be about 10^4 mean free paths in the shocked gas. Experimental observations of wave shape and position were also made in pentane-air and methane-air mixtures.

Two kinds of unstable combustion were observed in these experiments and in previous experiments with hydrogen. In one kind, the period of the oscillations was proportional to ignition delay time, suggesting an intermittent combustion at the front of the missile. The second kind was apparently an acoustic oscillation with period proportional to the sound wave transit time between the shock and combustion wave fronts.

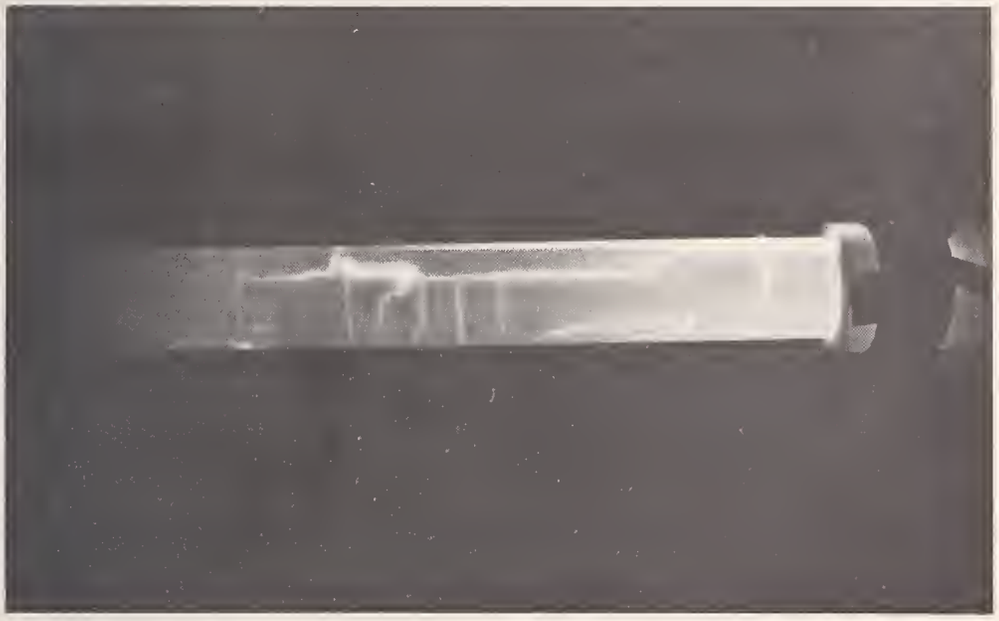
Reference Fuel Control Test Facilities Operated at the Bureau. Fuel controls are extremely complicated mechanisms used to control and meter automatically the fuel flow into gas-turbine aircraft engines under all conditions of flight. These units require extensive adjustment and test prior to installation to assure optimum aircraft performance. Necessary prerequisites for the satisfactory adjustment of such units are a high degree of absolute accuracy in fuel control test benches and standardized test procedures.

The Bureau of Naval Weapons maintains reference fuel control test facilities at the Bureau with which similar equipment used by industry and the military services may be checked for accuracy. In a typical program, reference fuel controls are calibrated at the fuel control manufacturer plant, at the engine manufacturer, and at the Bureau, and standardized test procedures are agreed upon. After good accuracy agreement is obtained between the Bureau and industry, the calibrated fuel controls are sent to naval overhaul stations for accuracy checks of Navy equipment.

The fuel control systems for nearly every model of aviation gas-turbine in operation in this country have been given these reference tests at the Bureau. As new engines and new model fuel controls are placed in service at the rate of about three each year, they are also included in this reference correlation program.

Static Electric Failure of Aircraft Engine Fuel Hose. Hoses containing an inner core of rubber or other suitable material and an outer covering of woven wire mesh are used extensively to interconnect the various fuel system components of internal combustion engines. Improved hoses, containing an inner core of a relatively nonconductive thermoplastic fluorocarbon were developed recently for high-temperature operating conditions. Many of these failed in service, however, as a result of the generation and discharge of static electricity produced by the flowing fuel.

Under the sponsorship of the Bureau of Naval Weapons, this phenomenon is under investigation. Results up to the present time show that very high electric potentials are produced when a nonconductive liquid flows within a nonconductive tube or pipe. The potentials are sufficient to produce electric arcs or sparks several inches long within the tubing. Also, these arcs penetrate through the walls of the tubing, resulting in pinhole punctures. Investigations are continuing to determine the influence of the properties of the fuel on the generation of static electricity, the maximum rate of charge that may be anticipated under operating conditions, and the desired level of tube conductivity by which such charges may be conducted safely to the ground.



Electrical spark discharges caused by the flow of a hydrocarbon liquid through a nonconductive plastic hose. The Bureau is conducting a study aimed at eliminating service failures in engine fuel lines which occur when the discharges puncture the line. **(See p. 43.)**

Reference Tables for a New Thermocouple To Be Established. Platinel II thermocouples, because of their good stability at intermediate temperatures, are rapidly gaining acceptance, particularly in the aircraft industry where base-metal thermocouples, due to exposure to oxidizing high-temperatures gases, are relatively short-lived. Because of this growing acceptance, the Bureau has undertaken to establish reference tables for Platinel II. These tables will be determined from observations on 27 separate thermo-

couples: nine thermocouples from each of three separate melts of materials. Each group of nine will consist of three each of 20-, 30-, and 40-mil wire.

Concurrently, work is continuing on stability studies in oxidizing atmospheres. It was found that Platinel II is relatively stable at temperatures up to about 2200 °F.

Flame Speed Inhibitors. Study of the effects of halogenated hydrocarbons on the flame speed of methane was continued. Halogenated hydrocarbons have long been used to extinguish fires, and the effects of these substances on flame speed may possibly be used as a means of testing their effectiveness. Methyl bromide, methyl chloride, and dichlorofluoromethane were examined as additives to methane-air mixtures, and of these, methyl bromide was shown to be the most effective in reducing flame speeds. The reduction of flame speed was found to be proportional to the amount of additive.

High-Temperature Thermocouples. Reference tables of thermal electromotive force versus temperature were completed for three iridium-rhodium versus iridium thermocouples in current use. Tables for the 40 percent iridium alloy were published and those for the 50 and 60 percent iridium alloys up to 3900 °F are ready for publication. Computations are in progress on the data for 10, 25, 75, and 90 percent rhodium for temperatures up to 4000 °F. It is expected that the optimum composition for an iridium-rhodium versus iridium thermocouple will be derived from the information obtained so far on the seven alloys.

2.1.3. ELECTRICITY

The Bureau's work in electricity is primarily the development, improvement, and dissemination of the standards of measurement for electrical quantities; and the study of the electrical and magnetic properties of materials. Electrical standards must be established that are constant over long periods of time, uniform throughout the Nation, and compatible with other standards used throughout the world. Measurements of electrical quantities directly in terms of length, mass, and time ("absolute measurements") are extremely difficult and are made only in the realization and confirmation of electrical standards of resistance, capacitance, inductance, and voltage; calibration work is done by comparison with these electrical standards.

A new section, Absolute Electrical Measurements, was established to separate calibration activity from fundamental measurement research. New procedures for realizing the electrical units via the volt and henry are being investigated.

Absolute Measurements. A group of portable 10-picofarad capacitors was built. One capacitor of the group was carried to the National Research Council (NRC) in Canada for comparison of the units of capacitance maintained in the two countries. Since both NRC and the Bureau obtain their units of capacitance from calculable standards of the Thompson-Lampard type, the comparison constituted a check on the accuracy of absolute

One of a group of transportable 10-picofarad quartz capacitors built for use in intercomparing NBS capacitance measurements with those of other laboratories. One intercomparison has already been made with the National Research Council of Canada, and showed that NBS and NRC measurements differed by only 2 parts in ten million. **(See p. 45.)**

capacitance measurements at the two laboratories. The comparison indicated that the capacitance units of the two laboratories differed by about two parts in ten million. Since the Bureau and NRC claim accuracies of only two or three parts per million, the agreement is much better than was expected.

Considerable progress was made in the development of an improved calculable capacitor. This project is expected to provide a calculable standard of capacitance accurate to at least one part in ten million.

The inductance analog of the Thompson-Lampard theorem was developed, and a preliminary study is being made of the practicality of a physical embodiment.

Continuing studies of the proton precession frequency and the Zeeman transition frequency indicate a high degree of stability for the ampere, as maintained at the Bureau with standard resistors and standard cells. Magnetic field perturbations in the solenoid used for this work were found responsible for some of the observed measurement fluctuations. A system of three-dimensional Helmholtz coils was constructed for use in a scheme expected to greatly reduce these magnetic perturbations.

Impedance of Dry Cells. An extensive study of the impedance characteristics of the most commonly used sizes of Leclanché dry cells and batteries was completed. The impedance was measured by a substitution method using a Wien bridge. The study covered the frequency range from 50 through 50,000 cycles per second (c/s) to determine changes in the

impedance of dry cells due to aging or use. The impedances of dry cells of different make, size, type, age, or state of charge vary widely, not only at a particular frequency but as a function of frequency. In some cases the impedance tends toward a maximum value at a particular frequency. In other cases, no maximum value is attained; the impedance increases throughout a decrease in frequency. Open-circuit voltages and flash currents and electrical capacities of the cells on standard tests were measured throughout the study to ascertain possible correlations between these parameters and impedance and residual capacity.

Battery Depolarizers at High Temperatures. To provide basic information on the stability of depolarizers (oxidizing agents) used in primary cells, studies were made of the thermal decomposition of manganese dioxide, the depolarizer used in the common dry cell, over the range from 440 to 640 °C. Manganese dioxide decomposes to form manganese sesquioxide and oxygen; the oxygen pressure varies logarithmically with temperature and reaches 135 atm at 640 °C. At higher temperatures (850 to 980 °C), the sesquioxide decomposes to form hausmannite and oxygen, with the oxygen attaining atmospheric pressure at 980 °C. From the measured dependence of the oxygen pressure on temperature and the known heat capacities of manganese dioxide, manganese sesquioxide, hausmannite, and oxygen as a function of temperature, a new value of −228,700 calories was obtained for the heat of formation of manganese sesquioxide. The data also yielded a new value of 36.8 cal/deg for the entropy of hausmannite at 25 °C.

Zener Diodes as Voltage Standards. Under a broad measurement program, the Bureau is investigating methods of accurately measuring the voltages of zener diodes, which are solid-state devices, in terms of saturated standard cells having electromotive forces known in absolute electrical units. Attention focused on the opposition method, wherein the diode voltage is measured in series opposition to that of standard cells with a precision of three to four parts per million. Temperature-compensated diodes having nominal voltages of 8 volts received the most study. As an adjunct to the measurement program, the Bureau has for two years been studying the long-range stability of zener diodes. In general, the stability is an inherent characteristic of the diode and may be affected by operating conditions and environment.

Membrane Potentials in Fused Salts. Reference electrodes or reference half-cells for use in electrochemical studies of fused salts are frequently isolated from the fused salt under study by fused silica or vycor. Apart from any ionic diffusion that may occur through the silica or vycor, interpretations of the voltages of galvanic cells, including the reference electrodes, may be in error as a result of neglect of potentials that may arise at the silica or vycor membrane. As part of an investigation to ascertain the magnitude of these potentials, the Bureau studied membrane potentials of silica and vycor in silver chloride–sodium chloride melts, maintaining a constant mole fraction of silver chloride on one side of the membrane but varying it on the other side. When the mole fraction of silver chloride

was varied from 100 to 10 mole percent on the variable side of a vycor membrane, the membrane potentials at 850 °C decreased from 540 to 9 millivolts. Thus, for a silver chloride reference electrode, silver chloride should be used as a minor constituent in a silver chloride–sodium chloride melt.

Differential A-C–D-C Transfer Standard. A new a-c–d-c comparator was developed to meet the growing need for more accurate, as well as more rapid, means for measuring a-c voltages at audio frequencies. The instrument can be used for the simultaneous comparison of an unknown a-c voltage with a known d-c voltage, eliminating the time lag between successive comparisons necessary with older forms of a-c–d-c transfer instruments that sometimes changed during the interval. It is ten times as accurate as an earlier differential voltmeter, although somewhat less convenient to use.

The instrument includes two identical rms voltage-sensing units, with electrical outputs connected in opposition through a detector. With their inputs connected to the same power supply, the units are adjusted to equality of output. They are then connected to the respective external a-c and d-c sources, with appropriate potentiometer and accessories to measure the adjustable d-c voltage. When equality of output is again obtained, the voltages of two sources are equal. Drifts and other changes in the units are self-compensating, so that a usable precision of 10 parts per million (ppm) can be obtained. The accuracy attainable depends principally on the a-c–d-c differences of the thermoelement in the a-c unit. Improvements now in progress in the basic NBS a-c–d-c transfer standards indicate that this difference is very probably less than 10 ppm from 50 to 2000 c/s and 1 to 500 volts, the frequency and voltage ranges in which there is the greatest demand for high accuracy.

Magnetism. The nuclear magnetic resonance absorption of Ni^{61} was observed in 1 percent Ni^{61}–99 percent Fe and 2 percent Ni^{61}–98 percent Fe solid solutions at 85.4 Mc/s at room temperature. The line width was about 700 kc/s in the 1-percent sample at room temperature, with some broadening in the 2-percent sample. At 77 °K the resonance occurred at 89.1 Mc/s with nearly the same line width as at room temperature. The intensity of the resonance signal decreased in an externally applied steady magnetic field. The room temperature hyperfine field at the Ni^{61} nucleus was 558 kilo-oersteds (kOe), assuming a nuclear moment of 0.3 nanometer (nm), or 186 kOe, assuming a moment of 0.9 nm. If the hyperfine field at the nickel nucleus is assumed to be nearly proportional to the local moment, a resonance frequency of 85.4 Mc/s implies a local atomic magnetic moment of about 2.0 Bohr magnetons at the nickel atom, somewhat less than that in pure iron.

The nuclear magnetic resonance of Ni^{61} was observed in 1 percent Ni^{61}–99 percent Co and 2 percent Ni^{61}–98 percent Co alloys. The resonance frequency was found to be 70.4 Mc/s at room temperature and 71.7 Mc/s at 77 °K. The hyperfine field at nickel in cobalt was about two and one-half times its value in pure nickel, implying a nearly proportional increase in the

local magnetic moment. The nuclear moment at Ni^{61} was determined to be 0.70 ± 0.04 nm by nuclear resonance studies in steady external magnetic fields.

A permanent adjustable standard of magnetic susceptibility was designed using the magnetic equivalence of a uniformly polarized volume of paramagnetic material and a solenoid carrying electric current. Such a standard was incorporated into a magnetic susceptibility bridge in a simple manner, surrounding the specimen; and the bridge was transformed into an absolute null instrument of high accuracy and sensitivity, and of great ease and low cost of construction and operation. By this method numerous particular advantages of other methods were combined, and some of their notable limitations were overcome. A preliminary application was made showing that the bridge performs as expected. A detailed consideration of sources of error suggests that it may eventually be possible by this method to obtain greater absolute accuracy than by other known methods.

An apparatus was constructed for determining absolute magnetic susceptibilities down to liquid helium temperatures by both the Thorpe-Senftle and the Gouy methods. Measurements were made by both methods on powdered samples of the same batches of $(NH_4)_2OsBr_6$, $HgCo(SCN)_4$, and $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$. Comparable accuracies were obtained by the two methods; however, about 3×10^{-2} as much sample was required for a Thorpe-Senftle measurement.

Magnetic susceptibility measurements were made on a series of hexachloro- and hexabromoösmates, M_2OsX_6, and on potassium hexachlororuthenate, K_2RuCl_6. The paramagnetism of the Os(IV) complexes is independent of temperature, and increases as the osmium ions are separated. The magnetic susceptibility and part of the optical absorption spectrum can be fit to theory by choosing the values of 2100 ± 100 cm^{-1} for the spin-orbit coupling constant and 2800 ± 100 cm^{-1} for the Coulomb interaction coefficient. It is shown that the effect of dilution is described by the equation $\chi = \chi\infty / (1 + \lambda d^{-n} \chi\infty)$, where $\chi\infty$ is the susceptibility at infinite dilution, d is the average distance between the osmium ions, λ is a constant, and n is approximately 2.

Dielectric Behavior of Liquids and Supercooled Liquids at Elevated Pressures. Apparatus was constructed to study the variation in dielectric constant and relaxation time of liquids and supercooled liquids at pressures up to 2000 atm. A specially designed thermostat enables the temperature of the dielectric cell to be accurately controlled and continuously varied from liquid nitrogen temperature (-196 °C) to about 50 °C.

The cell incorporates a novel design feature which permits the density of the material to be determined simultaneously with the dielectric properties. Thus, by suitable choice of temperature and pressure, measurements may be conducted under conditions of constant density in order to provide more definitive tests of dielectric theory. Measurements on a series of alkyl halides are planned to examine the correlation between dielectric relaxation and the liquid free volume.

Dielectric measurements on materials under high pressures provide a means for testing dielectric theory. **(See p. 48.)**

Precision Measurement of the Dielectric Constant of Solid Bodies. A new three-terminal dielectric cell was completed and used to make precise dielectric constant measurements by the two-fluid method, which does not require electrodes on the specimen. A special specimen of fused silica was prepared to check the method. The excellent results obtained showed that the dielectric constant of a well-made disk specimen can be obtained to within better than 200 ppm between 100 c/s and 50 kc/s.

In connection with this program, the guard gap correction was examined theoretically. This correction allows the effective area of a three-terminal electrode to be calculated with high precision.

The techniques of preparing dielectric specimens of polymeric materials were improved to the extent that disk specimens 8 cm in diameter can be prepared with a variation in thickness of only about 5 μ. This improvement is mainly the result of better control in use of the well-known Schieffer abrasion machine. Such accurate control of thickness is important in the precision of dielectric measurements.

Humidity-Time Studies of Dielectric Constant and Loss Index. In this continuing program, the dielectric constant and the loss index of a material were measured as functions of time after an initial abrupt change from less than 1.5 percent humidity to 52 percent humidity, or the reverse. Because of advanced developments allowing precision dielectric measurements without specimen electrodes, specimens without metal electrodes were measured and preliminary results obtained. Measurements are in progress on polystyrene, polyethylene, polycarbonate, polytetrafluoroethylene and its copolymers, and poly(1,4 cyclohexylenedimethylene terephthalate).

Theoretical Studies on Dielectrics. Theoretical work was completed on the relaxation spectrum of an Ising lattice with dipole-dipole interaction. In the simplest approximation with no interaction, such a lattice gives a single dielectric relaxation time. The present calculations show that dipole-dipole interaction leads not only to the anticipated principal relaxation time, but also to a set of shorter relaxaton times of lower intensity.

Chain-Folding in Polymer Crystals. Linear highly crystallizable polymers tend to crystallize in thin crystals (lamellae) having upper and lower surfaces that consist of chain folds. The polymer chain axes are perpendicular to the large flat surfaces. Such crystals are of great importance to understanding the mechanical and dielectric properties of semicrystalline polymers.

A detailed theoretical analysis of chain-folding in polymer crystals was made from the viewpoint of nucleation and growth theory. Fluctuations of fold length that occur during the growth of a layer were taken into account. The results cast some doubt on the existence of a "transition" in the growth rate near the melting point as predicted elsewhere. In certain limiting cases, the theory gives the same results as a simplified theory published earlier. In particular, the critical nucleus length fairly near the melting point is given by $l_o^* = 2\sigma_e/\Delta f + kT/b_o\sigma$. Because Δf varies as ΔT, the degree of supercooling, l_o^* tends to increase with rising growth temperature. ($kT/b_o\sigma$ is small compared to $2\sigma_e/\Delta f$.) A transition does actually take place in the growth rate at low temperatures (high supercooling), but this is not expected to be observable in most polymers.

The surface free energies, σ_e, of the chain-folded surfaces of polyethylene and polychlorotrifluoroethylene were estimated by both thermodynamic and kinetic methods. For polyethylene, σ_e is about 60 erg/cm^2; and for polychlorotrifluoroethylene, 35 erg/cm^2. Lateral surface free energies, σ, have also been estimated.

An experimental investigation of the change of thickness of chain-folded lamellae on storage at constant temperature was recently completed. The lamellae were found to thicken slowly on storage according to $(t) = l_o^* + B \log[(t-t_o)/\tau_o]$, where $(t-t_o)$ is the age of a lamellar crystal and τ_o, a time that is generally much smaller than $(t-t_o)$. In polyethylene, B ranges from about 45 to 65 Å per decade of time, depending on the temperature. A theory that explains most of this isothermal thickening effect was devised, giving B values in the range studied experimentally.

Dielectric Properties of Polymers. As part of the continuing program on the electrical properties of polymers, the dielectric properties of the new and interesting polycarbonate polymers are being measured over wide ranges of frequency and temperature. In general, the pattern set by the earlier complete study on polychlorotrifluoroethylene is being emphasized.

Dielectric Properties of Dipolar Chain Compounds. The dipolar derivatives of the *n*-alkanes (e.g., *n*-bromides, *n*-alcohols, and esters) behave as simple single-axis rotators in a crystalline field. In many cases, a state of hindered rotation appears abruptly at a sharp transition temperature in

the crystal (rotational phase transition). Dielectric studies on these materials provide a check on theories of dielectric constant and loss, and also give interesting information on the rotational phase transition. The rate of rotation is often very rapid, corresponding to dielectric relaxation times of 10^{-7} to 10^{-10} seconds. Work proceeded on instrumentation aimed at making accurate dielectric measurements in the 10 to 1000 Mc/s region on esters, bromides, and similar materials.

Molecules with spherical or near-spherical symmetry, such as $CH_3—C—Cl_3$ (methyl chloroform), also exhibit molecular rotation in the solid state. Dielectric studies on this class of materials are in progress.

Microwave Absorption in Compressed Gases. A systematic study of the nonresonant (relaxation) spectra of a number of gases consisting of symmetric top molecules (e.g., CH_3Cl and CH_3CN) in a variety of nonpolar foreign gas mixtures was completed. Well over 100 systems have been examined during the past year. Since the relaxation times are governed simply by bimolecular collisions at the densities in question, these data yield effective collision cross sections for molecular reorientation. With development of the theoretical interpretation of these cross sections now in progress, this work should provide a new and versatile method of studying intermolecular forces, especially the anisotropic contribution.

These 200-cm spheres were used to study sparkover voltages. Results were in substantial agreement with international sphere-gap tables. The range of 30- to 75-cm spacings between the spheres represented a voltage range of 750 to 1550 kv. **(See p. 52.)**

High Voltage. A study has been completed of the negative impulse sparkover voltages for 200-cm spheres at spacings from 30 to 75 cm over the voltage range from 750 to 1550 kilovolts (kv). The results obtained were in substantial agreement with currently accepted international sphere gap tables.

Other activities of a consolidating or preparatory nature included work on the 350-kv instrument transformer, the "Mighty Pike," for the Ontario Hydro Electric Power Commission. Work on the design of a compressed gas capacitor to replace the "Mighty Pike" represented further consolidation of this program for using capacitance dividers in voltage transformer calibrations. A second high-voltage d-c resistor was constructed to extend the range of our direct-voltage measurement capabilities.

Most effort in the program to develop improved techniques for the calibration of inductive voltage dividers, as well as in the joint effort within the Bureau in developing impulse voltage and current measuring techniques of importance in the study of exploding wire phenomena, has been directed toward the design, construction, and evaluation of equipment.

2.1.4. RADIO STANDARDS

The Radio Standards Laboratory is responsible for providing the central basis for electromagnetic measurements above 30 kc/s in the United States and for assuring international coordination of such measurements. The laboratory conducts basic research on physical principles and fundamental engineering techniques which have applications in the field of radio science. This research leads to the establishment, maintenance, continued improvement, and international coordination of a comprehensive set of national standards and precision measurement techniques for fundamental electromagnetic quantities. Extensive contact is maintained with other government agencies and with industry to keep pace with scientific trends which will establish future measurement requirements and to disseminate information concerning precision electromagnetic measurements.

In addition to the national standards, this laboratory provides new theories which radio scientists can exploit, new measuring devices which the instrument industry can produce, accurate design data for radio materials, calibration and broadcast services which furnish standards of radio measurement to hundreds of industrial and Government laboratories over the country, and consultation and instruction to assist other laboratories in the solution of problems in this field.

To better pinpoint the connection between measurement accuracies and the performance of major radio-electronic systems, the laboratory has begun a series of seminars in which speakers from industry are invited for one- or two-day meetings with laboratory personnel. Three seminars have been held so far and the results have proved very helpful in clarifying needs and priorities.

Because of the continued and increasing demands for electromagnetic measurement services, considerable work was done during the year in defining long-range plans for the Radio Standards Laboratory. Most of this information was presented in extensive series of tables and charts which outline the measurement and calibration capabilities now available and those which might be furnished within five years. Also, with the aid of a special appropriation, design work began on a new multi-million dollar building for the Radio Standards Laboratory.

Theoretical Physics. The far field of an antenna radiating into a half space may, in principle, be obtained from the two-dimensional Fourier transform of near-field values. However, the measurement of the near field may be affected in a complicated way by the characteristics of the measuring antenna. The theory was developed of a measuring antenna of arbitrary but known characteristics, under the assumption that multiple reflections between the measured and the measuring antenna are negligible. This work was motivated by a need for precise, inside-the-laboratory measurements on an electrically large aperture antenna in a microwave Michelson interferometer, but the results may be of wider interest.

In connection with the plasma physics program, correction terms to the equation-of-state of an ionized gas were obtained via new methods of quantum statistical mechanics. These results have led to a better understanding of the role of the basic particle interactions in a plasma.

RADIO STANDARDS PHYSICS

The Bureau's program in radio standards physics furthers the precise and fundamental study of physical constants and matter relating to radio science. It also establishes uniform, accurate standards of measurement in areas of frequency, time, and material properties, and disseminates these standards to the general public. The work is, for the most part, dictated by the requirements of the rapidly expanding electronic and space industries and makes possible a greater accuracy of performance by both private and Government agencies. The staff provides a readily available consulting service to industry, Government agencies, and individuals.

Fort Collins Standard Radio Transmitting Site. Construction is practically completed on the new facility at Fort Collins, Colo., which provides a transmission of standard low frequency (LF) and very low frequency (VLF) carrier signals with high phase stability. On July 5, 1963, the low-frequency station WWVB (60 kc/s) began transmitting from the new site near Fort Collins, Colo., with a radiated power of several kilowatts and with the carrier phase locked to the U.S. Working Frequency Standard. Time signals will be added and the carrier power will be increased within the next few months. Measurements near Los Angeles, Calif., and Chattanooga, Tenn., gave values of received field strength of about 150 and 100 microvolts per meter, respectively. Station WWVL (20 kc/s) began operating at the new site during the late summer. This station provides standard frequency signals and will serve as an experimental facility to develop tech-

View from halfway up one of the 400-foot towers supporting antennas for the new LF and VLF standard frequency transmitting stations at Fort Collins, Colo. The "helix house" (*center foreground*) contains the helical tuning device for the antenna. Furrows show the grid pattern of the ground wires. **(See p. 53.)**

niques using narrow-band signals to provide means for clock synchronization from a single station over wide areas of the world. The facility will also enable the Bureau to accelerate additional research, development, and services related to LF and VLF frequency and time broadcasts. Because of the high phase stability of LF and VLF signals, these broadcasts provide wide dissemination of frequency and time standards with a high degree of received accuracy. A large part of the cost of the 20-kc/s station was provided by the National Aeronautics and Space Administration.

WWVB and WWVL will not replace the shortwave transmissions of WWV and WWVH. The high-frequency signals require only simple receivers and their accuracy is sufficient to meet the needs of television and radio stations, electric power companies, amateurs, many businesses, and the general public.

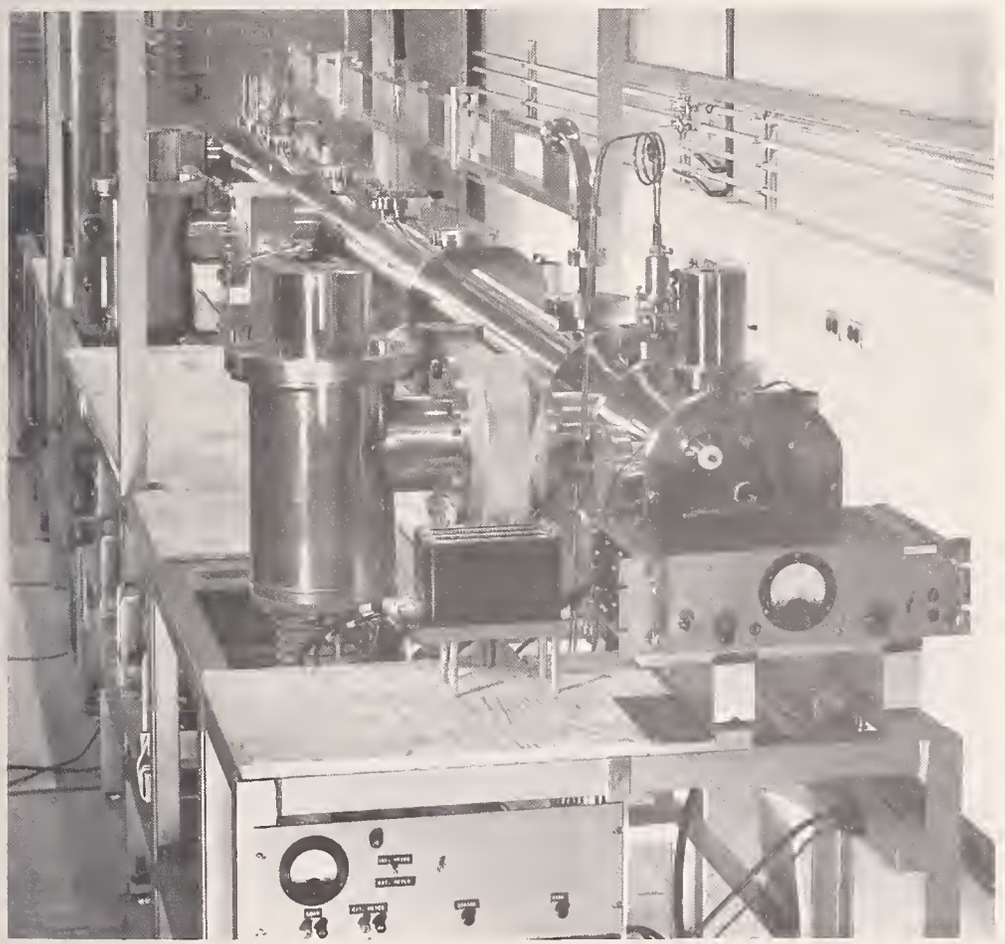
Atomic Frequency Standard Research. A new cesium beam frequency standard, NBS (III), has been completed. The spectral line width attained with this instrument is less than one-half (and the precision should therefore be about twice) that of NBS II. The NBS I cesium beam was converted to a thallium beam for the purpose of evaluating a thallium transition as the standard of frequency. Approximately the same precision is being attained with thallium as with cesium and it appears that an improvement of one order of magnitude in accuracy over that of cesium can be expected. A hydrogen maser, which is under construction, will also be evaluated as a primary frequency standard.

An NBS atomic time scale was established which uses the United States Frequency Standard as a basis. NBS atomic time was related to time pulses of WWV, to the atomic time kept by the Naval Observatory (A 1 Time), and to the time pulses of the Loran-C master station at Cape Fear, N.C. This

relation was determined to 5 microseconds by carrying a high-precision, quartz-oscillator clock from Boulder to these three stations. This comparison technique also gives the propagation delays between these three stations so that absolute time comparisons may be made continuously by means of propagated signals.

Theoretical work has been completed on the effects of high-intensity electromagnetic fields on atomic systems and the related effects of multiple quantum jumps, the Bloch-Siegert frequency shift, and frequency shifts due to the presence of a third state. Frequency shifts caused by the presence of additional signals in the excitation radiation have also been calculated theoretically.

Quantum Electronics. Research in progress in this area includes the measurement of the velocity of gamma-rays by means of the Mössbauer effect, the measurement of the fine structure constant by determining the fine structure separation in singly ionized helium, and a study of the various mechanisms of inducing blue fluorescence in anthracene with the red light of a "giant pulsed" ruby laser. Calculations have been completed on the intermediate field Stark effect in symmetric top molecules.



This new cesium beam frequency standard (which can also be used with thallium) is now being evaluated. Its length of 18 feet is about 8 feet longer than earlier models. This added length should significantly increase the precision. **(See p. 54.)**

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Radio and Microwave Materials. Materials research is designed to acquire an understanding of the magnetie (primarily ferrimagnetie), dieleetric, and eonduetive behavior of materials at radio and microwave frequencies in terms of the atomie eonstitution and structure of matter, and to improve and develop standards and measuring teehniques for determining material properties.

Magnetics. The change of elastie modulus with magnetization was investigated in a number of ferrites. The elastie modules first decreases and then increases with increasing external field for all of the ferrites investigated. This is a new result and is similar to behavior observed in niekel when measured by statie methods but not when dynamic methods are used. The decrease in the static modules is attributed to domain wall stiffness and a theory relating the two was developed. Fair quantitative agreement was found between the experimental observations and the predictions of the theory. Time-dependent demagnetization effects were also investigated for a number of ferrites. A rather low temperature eoeffieient of permeability as well as an anomalous disaccommodation effeet were observed in a cobalt substituted specimen. The ferrite speeimens of controlled composition which were used in these investigations were prepared by the NBS materials synthesis group.

Further improvements in initial permeability-measuring technology made it possible to cover the magnetic speetrum at radiofrequeneies using only the permeameter and a versatile variable-length eavity. Studies of the determination of gyromagnetie ratio and line width of polycrystalline ferrites showed that disk-shaped samples in rectangular TE_{102} cavities at *L*-band frequencies can be used in the same way as spherieal samples are used at higher frequencies. It appears that the disk teehnique is the best method to determine the gyromagnetic ratio and line width at these frequencies. However, it is neeessary to utilize demagnetization eorrections even for very thin disks, as was determined from an extensive study of ferrimagnetic resonance properties as a funetion of aspeet ratio. This indicates that numerous previous disk measurements may be in considerable error. The study of the disk technique was supported in part by the Navy.

A study of the mathematical representation of the complex tensor permeability was begun and quiekly led to a basic investigation of ferrimagnetic resonanee (FMR), espeeially of losses which may be related to spin waves, because FMR losses determine the line shape of the resonance and these losses in turn are often determined by spin wave effeets. Two new and important methods have been evolved for studying the FMR loss versus eoupling to the spin wave spectrum. In one, resonant ellipsoids of various ellipticities and orientations are used. The other requires intrinsic magnetie measurements at resonanee and away from resonanee on only one specimen shape (rod or sphere). Computer programs were prepared for eorrelating ellipsoidal data with intrinsie data. A roundrobin among various government and industrial laboratories was conducted on FMR and permittivity of 10 ferrite eompositions.

Magnetic resonance techniques are used to determine the magnetic energy levels, relaxation times, and transition probabilities of paramagnetic and anti-paramagnetic crystals. Thorough studies were made of the electron paramagnetic resonance (EPR) spectrum of a natural amethyst single crystal. The spectrum is extremely complicated and resists analysis by the usual crystal field methods; however, some information on the field splitting and the species of the ions was obtained. An important observation is that bleaching out of the purple color of the amethyst left the EPR spectrum essentially unchanged. The EPR spectrum of iron-doped synthetic quartz is also being investigated. A new method of comparing *X*-band and *K*-band cylindrical cavities for EPR work was developed.

Dielectrics. National and international roundrobin dielectric measurements were undertaken to help establish the present limits of accuracy for such measurements. High-temperature dielectric measurements received further attention, and the importance of this was emphasized by the meeting of an *ad hoc* committee representing 10 interested laboratories. Standard reference samples were further studied, resulting in selection of two glass compositions as standard materials for microwave frequencies. An available second-order perturbation theory for computing the permittivity of various samples in a resonator was investigated and gave rather accurate results. Preliminary results were obtained on the measurement of the dielectric constant of small spheres. Complex arguments become necessary for very lossy materials when expressing the complex dielectric properties of a material using complex propagation factors. A computer program was prepared for cavity techniques to be used in investigating lossy materials.

Mathematical investigations were undertaken of the feasibility of calculating permittivity and permeability of crystals based on their structure. Preliminary results are promising.

Conductivity. Whiskers of pure nickel of considerable length were prepared for the first time. Copper whiskers have also been prepared. Since whiskers are close to being "one-dimensional" single crystals, they are especially valuable for studying the effects of the surface on their electrical and magnetic behavior. Nickel-halide platelets have also been grown.

Materials Synthesis. Ilmenite-hematite solid solutions were studied by characterizing the dielectric and magnetic properties of the solid solution series $Ni_{1-x}Mn_xTiO_3$-Fe_2O_3. The electromagnetic properties of this system resemble those of the ferrites.

Plasma. A quantitative understanding of the basic physics of atoms and molecules in a high planetary atmosphere (essentially a plasma) is necessary for progress in physical interpretation of experiments and observations performed in these atmospheres. Such understanding is vital to the solution of basic problems of astrophysics and to the design, for example, of adequate systems of radio communications between earth and experimental vehicles.

During the past year observations of the magnetoresistance of plasmas were made, utilizing both plane-parallel and cylindrical electrode structures. The data agree in part with the theory, but the theory is suspect in the pressure

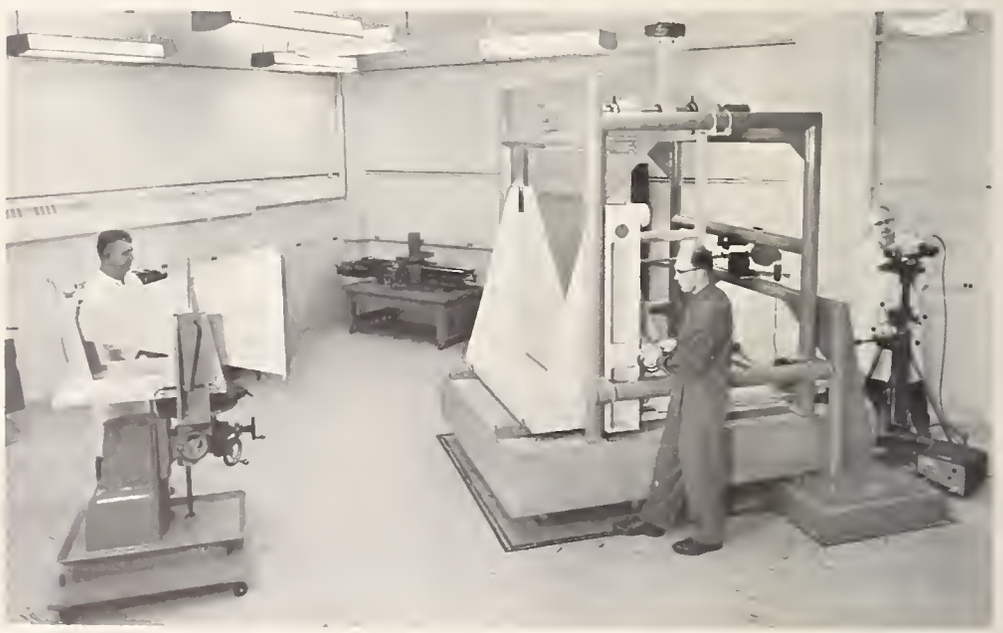
range in which magnetoresistance was observed. This work was supported in part by the Advanced Research Projects Agency of the Department of Defense.

Microwave Interactions With Plasma. Fast, accurate, and convenient diagnostic techniques are necessary to the understanding of processes of formation and loss of plasmas. A knowledge of such processes in turn permits the utilization of the plasmas as tools of the microwave and propagation engineer.

The surface wave diagnostic technique is being used to investigate nonlinear diffusion processes in a plasma in which the principal loss mechanism is wall recombination. The basic technique is being extended to a time-resolved measurement in order to look into the thermalized afterglow of a discharge. A Laplace transform technique has been developed to facilitate the spatial resolution of electron density in the surface wave determination.

Speed of Light (Diffraction Correction). During the year the effort applied to this problem was largely devoted to analysis and computation relating to the diffraction correction for the determination of the speed of light with a microwave Michelson interferometer. It was shown that (1) evanescent waves, (2) accidental mirror tilt, (3) variation of reflection coefficient of the mirror with angle of incidence, and (4) the component of the transverse electric aperture field perpendicular to the nominal direction of the field have no significant effect upon the diffraction correction.

Some speed of light measurements have been made with encouraging results. The standard deviation of a single measurement is of the order of 0.2 to 0.3 km/sec. It is expected that this deviation can be improved significantly for the final measurements.



Final tests are being conducted on this Michelson interferometer prior to measuring the speed of light at millimeter wavelengths. **(See p. 58.)**

Stark Voltmeter. The splitting of spectral lines due to the application of an elcctric field, which is called the Stark effect, offers an attractive possibility for measuring high voltages with high precision. During the year an apparatus employing this principle has been undergoing preliminary tests at voltages up to 5000 volts. This apparatus employs a Fabry-Perot resonator as an absorption cell for the observation of a rotational transition of methyl cyanide at 37 Gc/s. Short-time precisions of 1 or 2 parts in 10,000 have been obtained. In the next year the present, relatively crude, electronic circuitry will be replaced and other improvements will be made with the expectation that the precision will be improved by one or two orders of magnitude, as allowed by the theoretical limitations of the method.

RADIO STANDARDS ENGINEERING

The Bureau's program in radio standards engineering includes basic research on physical principles and fundamental engineering techniques having applications in the field of precision electromagnetic measurements. This research leads to the establishment, maintenance, continued improvement, and international coordination of a comprehensive set of national standards and precision measurement techniques for fundamental electromagnetic quantities in radio circuits. Dissemination of measurement accuracy is accomplished in large part through calibration services, and information on precision electromagnetic measurements is disseminated widely through publication, consultation, conference papers, invited talks, committee work with technical societies, individual visits to other laboratories, and the NBS-Air Force Working Group visits to Air Force contractors.

Low-Frequency Calibration. New instrumentation for the rapid calibration of volt boxes has been virtually completed. In the calibration of a number of units, this new console has reduced uncertainties resulting from random errors. All critical indications in the console are either digital or null-indicating, and all preliminary computations are performed automatically by a computer in the console. The operator needs only to add the data which are entered directly on a calculator.

The high-voltage facility now offers steady-state calibrations up to 50 kilovolts (kv) with an uncertainty less than ± 0.01 percent using direct current. Alternating-current calibrations up to 13.2 kv, with an uncertainty less than ± 0.2 percent at 60 or 400 c/s, can also be performed. The recent completion of a grounded safety enclosure and control console adds to the convenience of measurement and the safety of personnel.

The internal loading errors in inductive voltage dividers of a specific design were analyzed to provide a basis for the construction of 10- and 20-section dividers having known relative errors. A method of complementary measurements has been developed for the absolute measurement of certain nonzero errors in these dividers. The goal of this work, which is still in the experimental state, is a simple method for the accurate absolute establishment of alternating-voltage ratio over a wide frequency range.

Portions of the Wenner precision bridge have been insulated with Teflon and satisfactory measurements at 25 °C can now be made on 1-megohm standard resistors.

A new standard cell calibration console incorporates facilities for standard cell comparison and temperature determination of the regulated oil baths. By using both a microvolt potentiometer and a specially modified sensitive standard cell comparator, two operators at the console can measure independently and simultaneously the electromotive forces of standard cells.

High-Frequency Standards and Calibration. A method has been developed for calibrating high-frequency incremental air capacitors to an accuracy within 0.1 percent (limited mainly by their low-frequency calibration accuracy). In conjunction with this technique a dual twin-**T** high-frequency bridge is being constructed, and mathematical study indicates that the circuit constants may be adequately evaluated by using only calibrated capacitors. The basic accuracy of this bridge will then be limited by the accuracy of the incremental capacitors used in its calibration.

The assembly of an ultra-high-frequency coaxial reflectometer has been brought nearly to completion by the design and construction of a symmetrical four-port directional coupler and a coaxial tuner of incremental capacitance and constant inductance. An interesting sidelight, also in the coaxial field, is that according to measurements made by the laboratory the open-circuit fringing capacitance for a precision $\frac{3}{4} \times \frac{1}{2}$ inch air line, measured by a three-terminal method, is over 10 percent less than the computed value found in the literature.

Given conductors of any complicated shape, with uniform current density (direct current), their self-inductances and mutual inductance can now be calculated exactly from equations developed by the laboratory. This work has been extended to the high radiofrequencies with an approximating technique for evaluating the resistance and inductance of conductors with less complicated shapes. Using a high-speed computer, this method yields high accuracies.

By modifying the design of radiofrequency (rf)-voltage bolometer bridge mounts the accuracy of 300 to 1000 Mc/s sinusoidal unbalanced voltage measurements were improved from within ± 5 percent to within ± 1 percent based upon comparison with power measurements. Promising results were also obtained in extending the frequency upward, with accuracies of about 10 percent at 2000 Mc/s. Extension of calibration services is subject to development of stable interlaboratory standards and further verification.

Development of a balanced continuous wave (cw) rf voltage, and an rf current standard and associated measurement techniques, was nearly completed for frequencies to 1000 Mc/s. These are to be incorporated in NBS field-strength standards which are expected to be completed for these frequencies during 1964.

A noise power comparator system, designed to measure noise power from 10^{-18} to 10^{-21} watts with a precision of at least 0.02 percent, has been assembled and is undergoing preliminary tests. This improvement in sensitivity

and precision is expected through the use of a two channel radiometer (instead of the usual single-channel device) which has been developed by the staff.

Several types of very-high-precision noise sources are being developed to cover the needs of (1) high-level sources (up to 30,000 °K equivalent noise temperature), (2) moderate-level sources (equivalent noise temperatures within a few hundred degrees of room temperature), (3) low-level sources (equivalent noise temperature to 77 °K or lower), (4) variable impedance sources, and (5) ultra-high-precision, constant power, invariant impedance sources. Reference sources using emission-stabilized temperature-limited diodes and temperature-stabilized impedance networks in oil baths and furnaces have been constructed. Evaluation of these sources is in progress.

A mode filter was constructed for use in a 3.2-in.-diameter waveguide-below-cutoff attenuator. The filter attenuates the undesired TM_{01} mode by 98 decibels (db) and attenuates the desired TE_{11} mode by only 0.2 db.

Significant progress has been made in the development of temperature-stable thin-film resistive elements. The elements are made by the vacuum evaporation of a combination of metallic alloys. By proper control of fabrication parameters, the resistors are stable with full power dissipation under ambient conditions of 200 °C. The temperature coefficient can be controlled to values less than 50 ppm/°C. Resistors have been fabricated with values up to 350 ohms per square, and work is in progress to determine the maximum value obtainable.

The accuracy of rf voltage calibrations up to 30 Mc/s was improved by one order of magnitude, to within approximately 0.1 percent. This was achieved through improvements in the national reference standard and the installation of thermal voltage converters as working standards. Precision of measurement in the microvolt region was improved by one order of magnitude by installing new detecting devices in the microvolt calibrator.

New and extended high-frequency impedance calibration services include three-terminal capacitance at 100 kc/s, 465 kc/s, and 1 Mc/s for values ranging from 0.01 to 100 picofarads (pf), and the extension of coaxial measurements to frequencies as high as 1 Gc/s. In the area of primary standards, a computer program has been completed which yields the exact characteristic impedance of a coaxial line as a function of frequency. The computer program provides rapid evaluation and incorporates the Bessel functions for the corrections arising from the skin depth of current penetration.

In high-frequency attenuation, the upper frequency limit has been increased from 5.6 to 10 Gc/s, and the accuracy from 0.3 to 4 Gc/s has been increased from 0.1 db/10 to 0.05 db/10 over a 40-db measurement range. The calibration accuracies of loop antennas, in field-strength studies, have been improved from 5 percent to approximately 1 or 2 percent at frequencies up to 30 Mc/s. This is being accomplished by utilizing both "standard field" and "standard antenna" techniques. The frequency range of dipole antenna calibrations has been extended to 500 Mc/s.

Microwave Standards and Calibration. The international comparison of low-power microwave standards, begun in 1957, is being continued and, during 1963, Japanese measurements on NBS mounts agreed with NBS measurements to well within experimental error (0.5 percent). Improvements of the NBS facilities (current maximum error=0.2 percent), through reduction of noncomputable rf losses, were continued. Calibration service is being extended to other frequency bands.

The design of a microwave high-power calorimeter is well advanced. Testing and error analyses of the calorimeter and of an electron beam power meter is being continued. A subtle but important error associated with the use of the latter device has been discovered and analyzed. This error arises through the effect of the thermal velocity distribution in the electron beam on the magnitude of the reference current.

In recent years, the laboratory has offered reflection coefficient calibration services in several rectangular waveguide sizes. During the past year emphasis has been placed on extending these services to coaxial components. A thorough study of available coaxial connectors has identified two designs, one a commercial design and one the NBS-Woods design, either of which when assembled according to specifications contributes a reflection coefficient of less than 0.005 (VSWR less than 1.01).

Two reflectometer systems have been developed for measurements on coaxial devices—one is a hybrid system comprised of a coaxial precision line and associated elements appended to a rectangular waveguide reflectometer through a coax-to-waveguide adapter; the other is an all-coaxial system. The hybrid system has been thoroughly tested and has an accuracy equivalent to the existing waveguide systems. Components for the all-coaxial system have been developed and carefully tested. Their performance indicates that an all-coaxial reflectometer with an accuracy equivalent to existing reflectometers is possible, but tests must still be made on the total system. At wavelengths exceeding about 10 cm, the all-coaxial system will occupy less space than the hybrid system.

Development of a phase-shift-measuring system, utilizing a sliding short circuit as a standard, and capable of measuring phase shift to an accuracy of 0.01 degree, has been completed. This system has been thoroughly tested and is now ready for development as a national microwave phase-shift calibration service.

The development of the modulated subcarrier technique of attenuation measurement culminated during the year with the completion and submission of papers describing detailed analyses of the components. A system was constructed for study in the calibration center. Among the advantages offered by the modulated subcarrier technique of attenuation measurement are (1) only one oscillator is required, (2) relatively inexpensive but highly accurate audio voltage transformers can be used as attenuation standards, (3) phase information is readily obtainable with the same system, and (4) deviation of the detector from linearity becomes significant at higher power levels than in the case of the intermediate frequency (IF) system.

The development of millimeter-wave technology in recent years has extended the spectrum of useful frequencies, and the present rapid development of infrared and optical coherent sources presages a range of useful frequencies which will exceed by many times the range available now. Increasing effort, therefore, is being diverted to meet the demand for standards over this vast frequency range. A variety of components for use at approximately 40 and 70 Gc/s and part of a system for use at approximately 150 Gc/s have been acquired. A conventional 69.810-Gc/s reflectometer has been constructed and is undergoing tests. The sources have been phase-locked to the sixth harmonic of a phase-stabilized *X*-band generator, and an encouraging preliminary performance study of the millimeter wave reflectometer has been made.

A heterodyne receiver employing a phase-stabilized local oscillator has been provided for reflection coefficient and attenuation measurements at 69.810 Gc/s and a method is being developed for the measurement of millimeter wave power at about the one-watt level.

For microwave horn gain calibrations in the absence of "darkroom" facilities, a nanosecond (nsec) pulse technique has been developed. Tests using available components have shown that the system in its present state of development, employing 40-nsec pulses in a clear volume 60 ft × 60 ft × 20 ft, would be capable of an accuracy within 1 percent providing corrections could be made for any dispersion and bandwidth limitations of the horns to be calibrated. Application of the technique to waveform analysis is being considered.

The development of a calibration system which uses a transfer method of comparing bolometric power-measuring devices has led to a new calibration service for low-level cw power measurements in the frequency range of 12.4 to 18.0 Gc/s (WR62 waveguide). This system is the first in a series of microwave power calibration systems which are under development to utilize this method in the higher microwave region. During this developmental work, the implementation and procedure of this transfer method have been considerably simplified; it is expected that further refinements will be achieved as the work progresses.

The use of a new material for the hot-body source in the United States National Standard of microwave noise has resulted in considerable improvement in the operation of this standard and reduced the time required to stabilize the system to about one-fourth that which was previously necessary. The material, silicon carbide imbeded in beryllium oxide, was selected after study and experimentation with various possible materials.

Further work on the waveguide rotary-vane attenuator revealed an additional vane-displacement error caused by eccentricity and backlash of the mechanical gear train. Analysis has led to a precise method of specifying this systematic error. With this knowledge, the rotary-vane attenuator can now be used more accurately, and thus it might be that this attenuator will be useful as an rf attenuation standard.

A new transfer instrument, designed and built by the Bureau, is used for the intercomparison of microwave power meters. A bolometer unit is being calibrated. The insulated chamber (which is normally closed) stabilizes the temperature around the equipment. **(See p. 64.)**

A new approach to the fabrication of precision rectangular waveguide, in connection with the development of reflection calibration systems in several waveguide sizes, has resulted in improved accuracy of calibration for small values of reflection coefficient. The method consists of a "gage-block type" construction which allows partial adjustment to an exact rectangular shape, and it has provided a precision waveguide section in WR90 waveguide (8.2 to 12.4 Gc/s) with internal dimensions approaching a tolerance of ± 0.00005 in. and a precision waveguide section in WR62 waveguide (12.4 to 18.0 Gc/s) with a tolerance better than ± 0.00005 in.

Fabry-Perot Interferometer Used as a Dilatometer. A dilatometer which measures linear displacements as small as 10^{-7} cm has been developed. This instrument, based on the principle of the Fabry-Perot interferometer, is being used in studies of the static strain resulting from the magnetization of ferrites. It can also be used to determine the strains encountered in thermal expansions, the piezoelectric effect, or other phenomena in which the strains are similar in magnitude. Work on the dilatometer was sponsored jointly by the Army and the Navy.

In the interferometer, the specimen whose dimensional change is being determined is held firmly between an adjustable tailstock and a moveable table on which is mounted one mirror of the interferometer. A telescope, having a micrometer eyepiece for the determination of the change in diameter of the fringes, is used to form the interference pattern. When a strain

is induced in the specimen, the resultant movement of the mirror is detected as a change in diameter of one of the rings in the fringe pattern.

Using a mercury 198 light source, a mirror separation of 2.5 mm, and a telescope with a focal length of 25 cm, the magnification of the instrument is of the order of 10,000. For example, if the mirror moves 10^{-7} cm, the ring diameter changes by 10^{-3} cm, a change which can easily be measured.

2.1.5. HEAT

Heat measurements, standards, and related research play a most important role in modern science and technology. The Bureau discharges important responsibilities in these areas through the maintenance of the National standards for such heat measurements as thermal diffusivity, heat capacity, and heat of combustion. Internationally agreed upon temperature standards are maintained to assure a common scale upon which all temperature measurements are based. A strong research program aims to keep these standards adequate for the expanding scientific needs. In addition, supporting research on the physical properties of solids and gases at both low and high temperatures includes studies in low-temperature physics, statistical thermodynamics, high-temperature processes, high-pressure thermodynamics, and in various aspects of plasma physics.

An automatic thermocouple comparator has been put into operation, with substantial resultant increases in efficiency and reliability of the calibration procedure. Computer programs have been developed for analyzing low-temperature heat-capacity data and for calculating the thermal functions. The kinetics of a dissociation reaction have been established by combining shock wave techniques with time-resolved absorption spectrophotometry. A detailed calculation of the thermodynamic properties of ionized gases at high temperatures has been completed.

Molecular Energy Levels Program. The major effort in this program, which is supported in part by the National Aeronautics and Space Administration, is directed toward the accurate determination of the energy levels of small molecules. Information of this kind is of fundamental importance to the interpretation and understanding of phenomena that occur in environments at extreme temperatures or which are inaccessible, such as electric discharges, flames, the upper atmosphere, comets, and stars.

Recent work has emphasized the observation and measurement of the spectra of diatomic molecules in the vacuum ultraviolet region, from 1100 to 2500 angstroms (Å). The properties of the long-lived afterglows from electric discharges through nitrogen have been investigated in the vacuum ultraviolet. The spectra indicate that substantial numbers of very highly energetic nitrogen molecules emerge from the discharge region and retain their energy for long periods of time. The unusual conditions existing in certain regions of the afterglow have permitted observations of many vibrational states of the nitrogen molecule not previously detected.

An apparatus has been constructed for observing the vacuum ultraviolet absorption spectra of transient species produced by the flash photolysis of

gases. By using a flash lamp to produce a high-intensity, short-duration continuum it is possible to record absorption spectra of transient species from 1100 to 3500 Å, with time resolution as short as 10 microseconds.

Plasma Transport Processes. An apparatus for operating a magnetically confined low-pressure arc has been completed with the installation of a 125 kilowatt d-c generator to supply power to the magnet. The discharge column length is variable up to a maximum of 50 cm, and the maximum magnetic field is 7000 gauss. Study of the transverse oscillations of the plasma column, which are due to standing waves similar in character to Alfven waves, leads to estimates of the density and electron temperature which agree satisfactorily with information obtained from Langmuir probes and from relative intensities of spectral lines. The plasma density is between 10^{13} and 10^{14} cm^{-3} and the electron temperature about 5 ev for an 8-Å argon discharge in a 1300-gauss magnetic field. Under these conditions the ion temperature is roughly 1 ev.

Delivery of a 1.5-meter grating spectrometer was made and the specified performance obtained. The instrument was fitted with a punched tape recording system to facilitate use of the computer in obtaining radial intensity distribution functions by the Abel transformation. Examination of the departure from Saha equilibrium in the excited state populations of A II, and an estimate of electron density from Stark broadening of the Balmer lines of added hydrogen, are under way. The first intensity measurements show that excited state populations are above Saha (with respect to the electron continuum) for levels below about 21 ev.

Arrangements were concluded for Professor Susumu Takeda of the University of Nagoya, Japan, to spend a short period in residence to initiate experiments leading to an estimate of plasma density from the phase shift of a reflected microwave whose frequency is subcritical. The microwave equipment has been assembled and tested and is ready for measurements on the plasma.

Automatic Thermocouple Comparator. A thermocouple comparator has been developed which automatically records data during the comparison calibration of platinum versus platinum-rhodium thermocouples. This device, which places the data on punched tape prior to reduction by a computer, makes the calibration procedure more rapid and convenient, and eliminates the errors which may occur during hand recording and transfer of the data.

Use of the comparator permits automatic recording of the total electromotive force developed by the standard thermocouple and the difference between this emf and that of as many as 11 test thermocouples. The data can be recorded in several different sequences. One method is to set the comparator so that a complete set of readings is taken for every 0.5-millivolt change in the emf of the standard. Alternatively, readings can be initiated by clock control at preselected time intervals, or by manual control.

Both the emf of the standard and the difference emf's are converted from analog to digital form by means of shaft position encoders attached to self-

Automatic thermocouple comparator records data during comparison calibrations. The calibration information comes out on punched paper tape for computer input. Such automation enables the Bureau to provide more rapid calibration service, and permits scientists more time in which to perform the research necessary for more accurate measurements. **(See p. 66.)**

balancing potentiometer indicators. These digital data are transferred to a paper tape and, after processing on an automatic typewriter, put on punched cards. The data are then reduced by a 7090 computer, which fits an equation to the difference between the test and standard thermocouple emf's, combines this equation with that used to compute temperatures from the standard's emf's, and computes the emf developed by the test thermocouple at 1-degree (either Celsius or Fahrenheit) intervals.

Thermodynamic Properties of Light-Element Compounds. Under the sponsorship of the Advanced Research Projects Agency of the Department of Defense, the Bureau is continuing its comprehensive program of research on the thermodynamic properties of simple light-element substances which are important in rocket propulsion. The substances being specially investigated are the two-element and three-element compounds formed by beryllium, aluminum, and lithium with fluorine, chlorine, oxygen, nitrogen, carbon, and hydrogen. These substances are important combustion products of rocket combustion, and some of their properties are therefore being investigated over a very wide temperature range (0 to 6000 °K) and up to pressures of 100

atmospheres (atm). Nine research groups are engaged in a critical correlation of the available published data and in a systematic experimental program to measure new values.

An important part of the program is devoted to three types of thermal measurements on solids—heats of formation, heat capacities at low temperatures, and enthalpies at moderately high temperatures. The combination of these three properties makes it possible to calculate energies and thermodynamic stabilities of combustion products over wide temperature ranges. It was found that the most important substances under consideration for which these three properties had never been measured accurately are four two-element compounds (BeF_2, BeO, Be_3N_2, and Al_4C_3) and three three-element compounds ($BeAl_2O_4$, Li_2BeF_4, and Li_3AlF_6), and a program of determining these missing properties is continuing.

The high accuracy of these thermal measurements on three-element compounds has an additional, indirect advantage in practical applications. A unique opportunity is afforded to test the assumption which is commonly made that the properties of numerous such compounds of the same type, which in many cases have never been measured, may be estimated simply as the sum of those of the simpler compounds from which they were formed. For example, the heat capacity of $BeAl_2O_4$ was found to be equal, within a few tenths of one percent, to the sum of those for BeO and Al_2O_3 (measured earlier at the Bureau) for every temperature so far investigated (0 to 900 °C).

Other groups of the overall program are investigating the vaporization and gas properties of such substances as those above. One such group used a newly developed precise high-temperature "transpiration" apparatus to pass an inert gas over solid aluminum fluoride (AlF_3) and measure its vapor pressure. The heat of vaporization simultaneously found was combined with the heat of formation of the solid, measured by fluorine calorimetry earlier in the program, to give an accurate heat of formation of the gas. At the same time, the results substantiated a recent report that small amounts of the vapor are in associated form (Al_2F_6). The apparatus is being modified to study the thermodynamic properties of the hitherto unknown gases AlF_2Cl and $AlFCl_2$.

The final stage of experimental research of the above types is the critical correlation of its data with all other data and related properties, to yield an interconsistent and definitive set of tables of heats of formation and thermodynamic functions. The program is assuming this responsibility for the compounds of beryllium, aluminum, and lithium, and in so doing is participating in a permanent, fundamental activity of the Bureau.

Computer Analysis of Low-Temperature Heat-Capacity Data. In connection with a program to automate low-temperature heat-capacity measurements, computer programs have been developed to analyze the data and to calculate the thermal functions from the analysis. New data on various substances are being published at an increasing rate which are either more accurate than the older data or are on entirely new substances. The heat capacity is a complicated function of the temperature and no single form of

equation is known that can represent the heat capacity from 0 to 400 °K, the range of low-temperature heat-capacity data, for all substances with the accuracy attainable experimentally. A computer program has been developed to analyze the data using several overlapping equations, the best values in the region of overlap being selected "manually." To date, the literature data on over 80 substances have been analyzed and the thermal functions calculated from the data have been reported. A computer program that requires no "manual" operation is now being developed.

Thermal Diffusivity Standards. At high temperatures there is an urgent need for standards of thermal diffusivity and its closely related property, thermal conductivity, which is the product of thermal diffusivity and heat capacity. For poor heat conductors, microcrystalline glasses look promising in that they are opaque, are electrical insulators, and are available commercially as reproducible materials. Thermal diffusivity measurements were made to over 1000 °C on one microcrystalline glass. The measurements indicated that this material should be adequate as a standard up to 1000 °C, accurate to within several percent. For higher accuracies two precautions should be taken: first, the material should be heat-treated near 1000 °C to become completely reproducible, and second, care should be taken in using this material near 175 °C where there is a small transition in thermal diffusivity and some other properties.

Microwave Spectroscopy. A continuing program in microwave spectroscopy at the Bureau, partially supported by the Office of Naval Research, is concerned with measuring the radiofrequency and microwave spectra of diatomic molecules, with particular emphasis on those molecules that are known to be present in the interstellar gas. Precise knowledge of their spectra is necessary before these molecules can be searched for and studied by radio-astronomical methods. Recently, laboratory measurements were made on the low-frequency (approximately 100 Mc/s) line spectrum of the molecular radical SH, generated by the chemical reaction of atomic hydrogen with hydrogen sulfide gas. Similar chemical techniques are being investigated as means of producing and studying other radicals of astrophysical interest, such as CH and SiH.

Nuclear Orientation. Studies made of the photoneutron cross section in the region of the giant resonance, using an alined holmium target, directly confirmed the theory that this cross section is associated with the two axes of the deformed nucleus. This experiment, aside from the importance of demonstrating this phenomenon, was the first successful experiment using an oriented nuclear target with an accelerating machine. The work was performed at the NBS Betatron Laboratory in collaboration with the High Energy Radiation Laboratory. The alined holmium target was obtained by cooling a large single crystal of holmium ethyl sulfate to 0.29 °K with the NBS portable He^3 refrigerator.

Shock Wave Reaction Kinetics. Work has been completed on an experimental investigation of the kinetics of the dissociation reaction $N_2F_4 \rightleftarrows NF_2$. The experiment involved the combination of shock techniques with

time-resolved absorption speetrophotometry. The experimental data show that the reaction proceeds by a unimoleeular meehanism. The experimental aetivation energy was 19 keal/mole at a total concentration of 6×10^{-2} mole/liter over the temperature range 343 to 410 °K. (The dissoeiation energy is 19.8 keal/mole.) The Arrhenius frequeney factor in the high-pressure limit was estimated to be 2×10^{15} see^{-1}. This result indieated that free rotation about the N–N bond probably occurs in the energized activated eomplex.

An experimental determination of the absorption eoeffieient for the optieal transition that the difluoroamino radical (NF_2) undergoes for light at a wavelength of 2602 Å was determined at temperatures between 438 and 870 °K. The mean result was 535 liters/mole em.

Thermodynamic Properties of Gases at High Temperatures. A reasonable approach has been sought for the caleulation of thermodynamie

Apparatus used in the determination of the spectra of diatomic molecules thought to be present in interstellar gas. Precise determination of the line frequencies is necessary before such molecules can be searched for and studied by radiotelescopes. **(See p. 69.)**

properties of ionized gases at high temperatures, in a study sponsored by the Air Force Special Weapons Center. This includes a treatment thought to be satisfactory for atoms and atomic ions in circumstances of interest in magnetohydrodynamics as well as for more usual equilibrium conditions. In the past, some approaches have encountered computation difficulties related to the divergence of the partition function of an isolated atom. The present practical solution of the problem uses the fact that under the frequently plausible conditions of Debye screening, the number of states available for occupancy can be estimated easily in a semiclassical approximation. For a first approximate calculation scheme, the energies of hydrogenic levels have been taken as modified by Debye screening according to first-order perturbation theory. The levels are broken off where their available number agrees with the semiclassical estimate. As the behavior of the screening is different at different concentrations of ions and, as it also depends on temperature, there is a joint influence on the partition function and so on the thermodynamic properties. It is only by a careful accounting of the appropriate derivative relations that the otherwise unknown thermodynamic effects of these dependences can be taken into account. Programming is in progress to perform the required operations in a systematic manner via electronic computer.

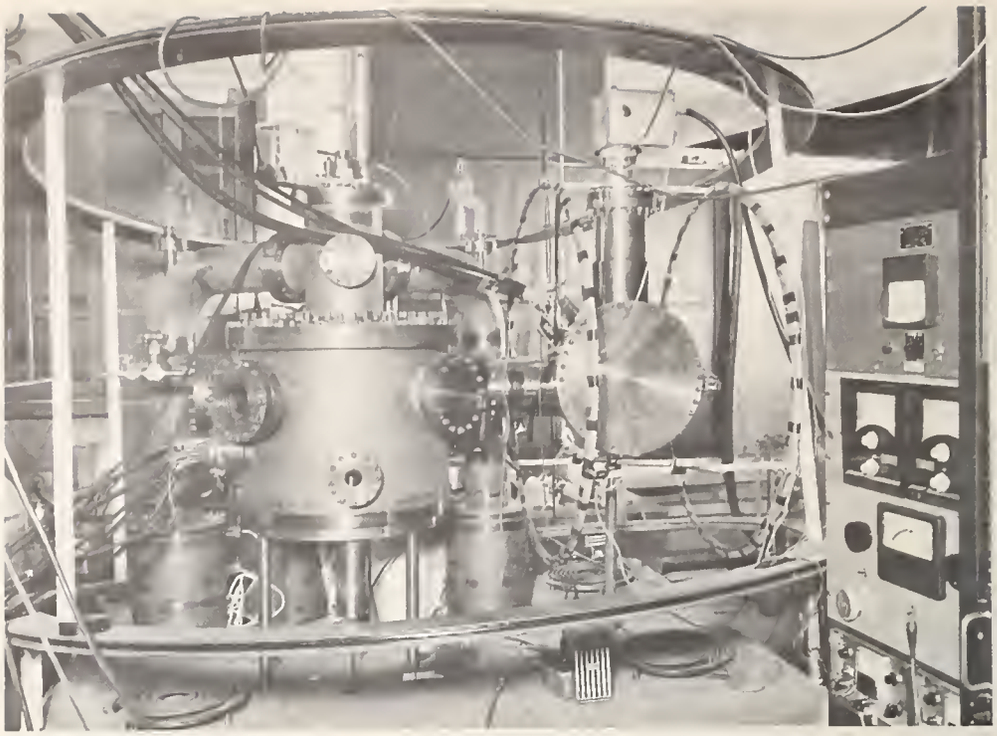
A study of the partition function for diatomic molecules at high temperatures has similarly been in progress according to a second virial type formulation. This has application also to intermolecular interaction effects.

2.1.6. ATOMIC PHYSICS

Atomic physics reserach has continued to be oriented primarily toward the determination and evaluation of fundamental data relating to atomic properties and interactions and toward a more basic understanding of the phenomena involved. The major portion of this work is of primary interest to the fields of plasma and astrophysics, although the data derived have a wide area of application in physics, astronomy, chemistry, and engineering. The Bureau, with partial sponsorship of the Advanced Research Projects Agency (ARPA) and the National Aeronautics and Space Administration, continues to be a major international center for research on atomic properties, and the accumulation and evaluation of the published literature in its two data centers on atomic energy levels and atomic transition probabilities represent valuable contributions to the scientific community.

In the materials field, properties of semiconductors are under study in a continuing extensive research program partially sponsored by ARPA. This research is now being augmented by a study sponsored by the Atomic Energy Commission of the optical properties of thin films in the vacuum ultraviolet region.

Continuum States in Rare Gases. New information on the atomic structures of helium and some of the other rare gas atoms was obtained in a series of independent experiments which utilized both electron and



Studies of electron interactions in the rare gases have yielded a new and fundamental insight into the character of energy states in these gases. The interactions occur in the large cylinder (*center*). See p. 71.)

photon interactions. These experiments yielded a self-consistent picture of the higher energy levels in these rare gas atoms, and theoretical studies gave a new and fundamental insight into the character of energy states in atomic continua.

Photons produced in the vacuum ultraviolet spectral region by the accelerated electrons in the NBS 180-Mev synchrotron were utilized in studies of the absorption properties of several of the rare gases. The ultraviolet radiation obtained from the synchrotron is the only known pure continuum available in this energy range, and it is well-suited to the study of the detailed absorption processes in the far ultraviolet.

A series of absorption features were observed in helium gas, at energies some 35 volts above the energy necessary to ionize the neutral helium atom. At these energies, two competing processes can take place: the ultraviolet photon can either remove one of the electrons completely from the atom, or can leave the atom in a short-lived neutral state by elevating both its electrons to higher excited states. Since these two processes are strongly mixed, the observed spectrum exhibits the anomalous features characteristic of autoionized states.

Theoretical studies of the absorption characteristics of helium showed excellent agreement with the observations, and have led to a greatly improved understanding of atomic energy states that are mixtures of discrete and continuum states. New calculations for a series of autoionizing levels in helium indicated that relatively crude calculations can be expected to

predict level widths within a factor of two or three of experimentally determined values.

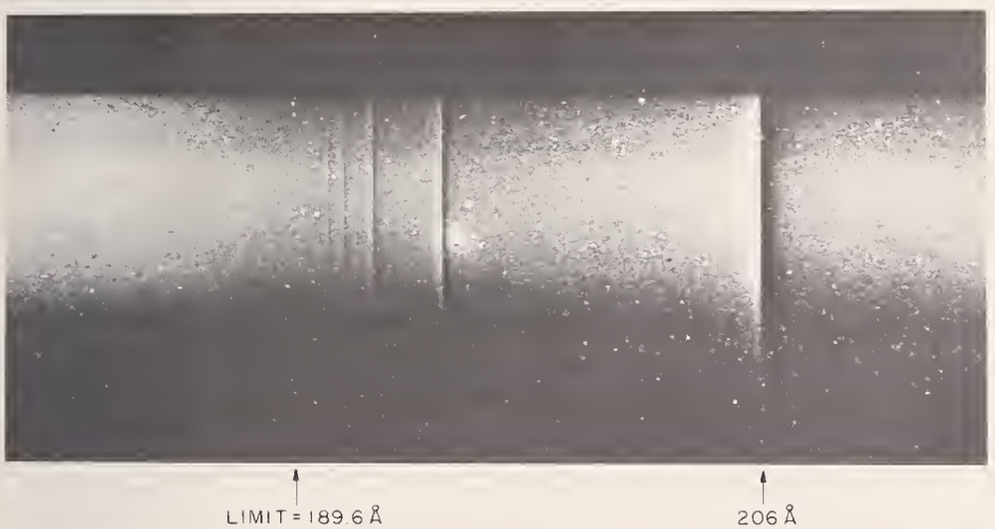
These same atomic states in helium were also studied through observations on the energy losses suffered by nearly monoenergetic electrons passing through helium gas. These measurements were performed with new apparatus designed to measure electron-scattering cross sections in the range from 500 to 5000 electron volts. This apparatus will be used to make further accurate and detailed studies of electron-scattering cross sections for various atoms as functions of both angle and energy.

Characteristics of energy losses of electrons scattered by helium were in complete agreement with results of the experiments performed with the ultraviolet photons from the synchrotron.

A new and extremely monoenergetic electron gun and an analyzer were constructed and utilized in studies of the absorption characteristics of rare gases. Experiments performed with this apparatus in helium gave evidence of an anomalous transparency to low energy electrons. The observed "window" in the helium gas was extremely narrow, and lay well below the energy of the first excited state.

In addition to those of helium, the absorption characteristics of neon and argon were studied in both the photon and electron experiments. In each case, results qualitatively similar to those described for helium were observed. Numerous autoionizing states were identified, and in neon two resonances below the first excited state were observed. No such low-lying states were seen in argon, however.

These studies are expected to yield data on the generalized oscillator strengths in the continuum and to lead to an understanding of these states. The results will be of fundamental interest to both astrophysicists and plasma physicists, and are necessary to the interpretation of astrophysical and thermonuclear phenomena.



Absorption spectrum of helium obtained using the NBS synchrotron as a source of light. The ultraviolet radiation from the synchrotron is the only known pure continuum available in this energy range. **(See p. 71.)**

Plasma and Astrophysics. The Bureau continues to be the world center for the collection and determination of much of the atomic data needed by atomic physicists and particularly by plasma and astrophysicists. Such data are important to the proper diagnostics and understanding of processes occurring in hot gases. Work in this field was supported by ARPA and the Bureau.

In addition to the work mentioned in the previous section on continuum oscillator strengths, work on the determination of the discrete oscillator strengths (or transition probabilities) in atoms continued.

Research continued on use of the wall-stabilized arc for the measurement of transition probabilities. The shifts and widths of several oxygen lines were measured, and the results are in good agreement with recent theories on line broadening in dense plasmas. This method represents a new and simple way of analyzing dense plasmas of heavy elements, and should lead to a better understanding of high-temperature plasma phenomena.

The cross section for elastic scattering of the slow, 1-ev electrons by hydrogen atoms was measured by the electrical conductivity method. In contrast with earlier experimental measurements by research groups elsewhere, the result agrees well with recent theoretical values and confirms the general consistency of the spectroscopic analysis of the hydrogen plasma.

The relative transition probabilities for a number of lines of singly and doubly ionized oxygen were determined utilizing a magnetically driven shock-tube. The results agree very satisfactorily with the theoretically obtained values. No attempt was made to present absolute values, as attainment of complete local thermodynamic equilibrium was somewhat uncertain.

Modified Hartree-Fock calculations of transition probabilities were completed for the major transitions in two- and three-electron atoms and ions. Relative transition probabilities were calculated with the Racah methods for the spectrum of doubly ionized vanadium.

Atomic Energy Levels. Emphasis continued to be centered on the observation and analysis of the rare-earth spectra. Extensive laboratory observations, including the strong absorption lines and Zeeman patterns, were carefully scrutinized to determine the ground state and over 100 "even" levels for Ce I. The spectrum of Ce III was observed with a sliding spark, and measured from 700 to 1100 angstroms (Å). Some 2000 lines are known, of which 75 percent are now classified. The strongest line of Ce III, λ3055.589 Å, may possibly be present in the solar spectrum, where an otherwise unidentified faint line has been observed at λ3055.594 Å. If this identification is correct, it provides the only evidence of a third spectrum among the solar lines $\lambda > 3000$ Å.

Measurements and calculations of the Zeeman patterns of 1307 lines in the first three spectra of ytterbium were compiled preparatory to a new description of these spectra comprising more than 6500 lines. Measurements of approximately 10,000 lines of Tm I, Tm II, and Tm III were made, covering the interval 2300 to 11000 Å.

A new edition of the extensive solar spectrum table is near completion.

Highly accurate measurements were made of lines in the spectra of Krypton 86 and Mercury 198 for use as secondary wavelength standards. The orange-red line in the spectrum of Kr_{86} has been the International Standard of length for more than three years. **(See p. 75.)**

A theoretical study on the nonlinear effects in the spectra of elements in the iron group contributed significantly to the understanding of the electronic configurations in these atoms.

Wavelength Standards. The program on mercury atomic beams and Zeeman filters, undertaken in connection with the redefinition of the meter, concluded with experiments comparing the wavelength of the 2537 Å line as obtained from these two sources. Highly accurate wavelength measurements of additional mercury and krypton lines suitable for standards were also completed.

Infrared Spectroscopy of Gases. The infrared absorption of a band of carbon suboxide (C_3O_2) was measured under high resolution. Analysis of the spectrum provided the first unambiguous evidence that this molecule is linear and must have an unexpectedly low bending frequency. A parallel band of ethane-1-C^{13} was also analyzed. The results are in agreement with C—C bond length measurements obtained for propane.

A forbidden vibronic band of NO that was predicted to have a transition probability produced by the interaction of the two electronic states was observed. Both frequency and intensity measurements were made. Within experimental error, the intensity of the band was found to be the same as that predicted theoretically.

Measurements and a partial analysis of 15 absorption bands of CH_3D were completed as part of an AEC-sponsored program of measurements of deuterated compounds. Under the same sponsorship, measurements and analysis of a number of bands of DCN were completed. This work complements a recently finished analysis of the spectrum of HCN. In addition to furnishing values of potential constants and rotational constants for two isotopic species, the work on HCN and DCN emphasized the importance of including certain higher-order constants in the analysis so as to achieve satisfactory agreement between the observed and calculated spectra. Such higher-order terms were previously unnecessary, but the advent of higher resolution and more accurate measurements has necessitated use of more exact expressions for the energy levels.

Shapes of Rotational Lines as Influenced by Pressure. Measurements were made on the pressure broadening of infrared absorption lines for the gases HCl, DCl, CO, and HCN. In addition to some self-broadening measurements, broadening by various types of foreign gases was investigated. The broadening has been demonstrated to be nearly independent of the vibrational level involved, although it does depend on the rotational level. The most significant work involves the measurement of the broadening of HCN lines due to the pressure of HCl. These two molecules have a large dipole moment and thus strongly interact when they approach each other. This work was supported by the Cambridge Air Force Research Center and the AEC in addition to the Bureau.

Absorption Spectra of Solids. The infrared spectra of several very interesting solids were completed or are now under study. Infrared studies of the compound $4CsCl \cdot 3HCl \cdot 3H_2O$ and its deuterated counterpart were used to show that, contrary to previous expectations, they do not contain the HCl_2^- ion but only the ions Cs^+, Cl^-, and H_3O^+. Work is in progress to determine if the elusive HCl_2^- ion is present in certain pyridine salts.

Spectra of polyhalide compounds were also analyzed. These compounds are similar to the recently discovered rare gas compounds (i.e., XeF_2) and are of great interest. The Bureau is uniquely suited for studies of polyhalide compounds because of the availability of spectrometers which can be used in the far infrared region where these spectra are found.

Solid State Physics. The research program in solid state physics, which is partly supported by the AEC and the ARPA, concentrates on four major interdependent areas: electronic transport, optical characteristics, magnetic resonance, and dielectric properties. This experimental program is supported by theoretical studies and by crystal growth and structure investigations. The main emphasis is on a group of semi-insulators and semiconductors (namely, the Ti-O compounds: Ti-oxides and titanates) which have important uses in many different fields (such as dielectrics, masers, phototropic materials, etc.). Other substances under investigation are spinel, CdTe, PbF_2, and several azides.

A study was made of the electron spin resonance spectrum of molybdenum in rutile. Fine structure, hyperfine structure, and superhyperfine structure

were observed and interpreted. Use of circularly polarized microwave radiation enabled the unambiguous determination of the sign of the g-factor.

Measurements of the Seebeck coefficients of TiO_2 and $SrTiO_3$ down to 15 °K have shown that the phonon-drag effect contributes most to the value of the coefficient of rutile at low temperatures, while it seems to be absent in $SrTiO_3$.

Electronic energy band calculations for TiO_2 indicated that the conduction and valence band of this material are mixtures of Ti-3d and O-2p orbitals. The binding is not completely heteropolar in nature. Qualitative agreement with many characteristics of the substance can be obtained (energy band gap, width of valence band, higher conduction bands, etc.). A similar calculation for cubic titanates (perovskites) is in progress.

The optical spectrum of Co in a Mg-Al-spinel crystal can be interpreted in terms of calculated level schemes (crystal field theory). The measurements confirm that Co prefers the tetrahedral site rather than the octahedral one.

The nitrogen nucleus in azides (NaN_3, KN_3, HN_3) is being investigated by means of nuclear magnetic resonance and quadrupole resonance techniques. The quadrupole coupling constants of each of the three N nuclei in HN_3 were determined from the microwave spectrum.

Good crystals of CdTe were produced using the Bridgman method; the photoelectric properties of this substance are being explored.

Electron Optics. A problem which has plagued electron physicists for years is the production of well-collimated electron beams of low energy. Such a beam is a basic requirement in almost every experiment in electron physics and in many in atomic physics. A new and somewhat novel analysis of the physics involved in the production of such beams has given rise to the development of a series of electron guns of precise design. These guns, which perform much better than previous designs, were utilized in the previously described study of energy losses in rare gases.

Measuring Velocity of Light. A multifaceted program was instigated to remeasure the velocity of light to at least one more significant figure. The method involves the measurement of beat frequencies between two optical lines emitted from a helium-neon laser. A comprehensive study to determine the feasibility of detecting and measuring beat frequencies of the order of 10^{12} cycles per second between two optical lines in the helium-neon laser was successfully completed. An experimental investigation was initiated by Egerton, Germeshausen & Grier, Inc., under contract to the Bureau to determine the necessary design considerations involved in the construction of a modified cathode-ray tube for the beat frequency measurement.

Two helium-neon lasers have been constructed to investigate the various methods of stabilization of the laser lines. These lasers are also being used to investigate the various lines available for and most suitable for the beat frequency detection.

Optical Pumping. For the past year, work progressed on an experiment to pump xenon 129 optically at 1469 Å. A strong resonance lamp was designed and constructed to give a radiation flux of approximately 10^{15} photons/sec per steradian at 1469 Å with no appreciative self-absorption.

The radiation is emitted through a sapphire window fused to the lamp. Experiments are now in progress to detect the optically pumped signal in xenon 129.

Magnetic Moment of the Proton. An experiment was undertaken to determine the magnetic moment of the proton in units of the nuclear magneton. It is hoped that this determination will lead to the resolution of a 50 ppm discrepancy in this constant reported by various investigators.

Experimental Atomic Collisions. A new instrument for the study of photodetachment of negative ions is being completed. This instrument will provide significantly greater resolution of both the ion beam and the photon beam. Studies of the behavior of the cross sections near threshold for photodetachment of atomic ions will be undertaken without the assistance of prior theoretical assumptions.

2.1.7. RADIATION PHYSICS

The radiation research program of the Bureau is directed toward meeting technical needs in three general areas: radiology, nuclear science and technology, and radiation processing. For example, medical radiologists are requesting improved accuracy in the determination of source output and absorbed dose. Since the calibration of clinical instruments is usually two steps removed from the national standard, and since the transfer instruments presently available have rather low precision (maximum effect of random errors being of the order of 1 percent), it is desirable to increase the accuracy of the national standards. The NBS transfer instrument that is now used for national and international comparison has an accuracy of 0.2 percent, and extensive research efforts continue in this area.

Demands from research workers for more accurate cross sections and for more information about the nature of the interaction between radiation and materials have resulted in an expanded program in these areas. In addition, research laboratories require radioactivity standards accurate to within 1 percent; such accuracy is difficult to attain but is being provided with special effort.

Increased applications of radiation in industry for such purposes as preservation of foods, crosslinking of polymers, sterilization of sutures, and activation analysis have created a need for improved standards and dosimetry at high radiation energies and at high dose levels. Industrial applications require measurements somewhat less accurate than those required for medical or nuclear research applications, but beams whose intensity is usually of the order of kilowatts of radiation power create severe measurement problems.

Considerable effort is currently being applied to the design and construction of equipment which will be used to implement an enlarged research program in the new laboratory facility at Gaithersburg, Md. Sources with higher intensity, such as the NBS 100-Mev linear accelerator (Linac) and the 1.5- and 4-Mev direct accelerators which will become operational in 1964, will make it possible for the Bureau to meet the increased demands for basic experimental data, improved standards, and refined measurement techniques.

X-Ray and Gamma-Ray Dosimetry

Cavity Chambers. Instruments used as laboratory standards for X- and gamma-ray measurements by medical institutions, research laboratories, manufacturers, atomic energy installations, the Military, and Civil Defense, are calibrated by comparison with the Bureau's standard instruments. The accuracy requirements for these calibrations have been steadily increasing. Close agreement between NBS standards and those of other countries is also important. Accordingly, improvements have been made in the Bureau's X-ray free-air-chamber standards, in the calibration accuracy of gamma-ray beams, and in diaphragm sytsems for evaluating stem corrections in certain types of radiation instruments.

Photographic Dosimetry. Work continued on extending photographic dosimetry to exposures of 1 milliroentgen (mR) or less of high-energy X- and gamma-radiation. Post-exposures to 620-millimicron infrared radiation, chemical treatment of the films, and special development techniques extended the range downward by close to a factor of ten. Microphotographs showed that this extension is achieved by an increase in grain developability (larger number of grains developed at any given exposure), an increase in the projected area of the grains, and a general change in grain shape.

Further experiments were performed on films that had been exposed to two widely different rates of gamma radiation and, after development in a surface developer, had shown marked reversal and re-reversal effects. Most of the work on these films during the past year was done at the Armed Forces Institute of Pathology (Biophysics Branch). The measured quantities, i.e., developed silver per unit density (the photometric equivalent), mass of developed silver per grain, and density per grain (proportional to the densitometrically effective projected grain area), were studied for both intensities as a function of exposure. Anomalous behavior was found for the number of grains in the ascending branch of the density-versus-exposure curve obtained with high intensities, and for the photometric equivalent at the re-reversals for the very highest exposures both with high- and low-intensity radiation. Conclusions were drawn from these findings concerning the cause for the rate dependence of the maximum density attainable, and for re-reversal.

A review paper on the use of photographic film for personnel dosimetry was presented at the Symposium on Personnel Dosimetry Techniques for External Radiation, held in Madrid under the sponsorship of the European Nuclear Energy Agency.

Solid State Dosimetry. The investigation of the response to X-rays of silicon radiation detector cells of the diffused p–n junction type, when operated as photodiodes and photovoltaic cells, was continued. Different cells of the same type were investigated and methods of measurements were improved in order to provide increased accuracy. The temperature dependence of the photocurrent produced by X-rays was measured between 25 and 50 °C and found to be similar to that observed for photocurrents produced in silicon photocells by visible light. Measurements of the energy dependence of the generated photocurrent were extended to moderately and lightly

filtered X-rays of half-value layers between approximately 0.07 mm and 16.0 mm aluminum. Preparations have been made for comparative measurements of the response to X-rays of silicon radiation detectors of different types.

Response of Silicon Charged Particle Detectors at Low Temperatures. A program to investigate and develop solid state counters for nuclear physics experiments is under way. Recent measurements were carried out to investigate a suggestion that Li-drift detectors should function as well near absolute zero as at elevated temperatures. The results of two dissimilar experiments, designed to eliminate contact anomalies at low temperatures, indicate that the response exhibits a sharp decrease at a temperature of about 30 °K. Subsequent measurements with a silicon surface barrier detector of 3000 ohm-cm resistivity show that the anomalous region for this relatively undoped silicon extends from about 17 to 25°K. Corroborative experiments and experiments to confirm recent theories as to the physical origin of the effect are in preparation. Beyond the interesting solid state physics implied by this work, an appropriately doped silicon detector and beta-emitter with a simple charge-sensitive preamplifier and integral discriminator may have possibilities as a very accurate and convenient secondary temperature standard.

Radioactive Sources

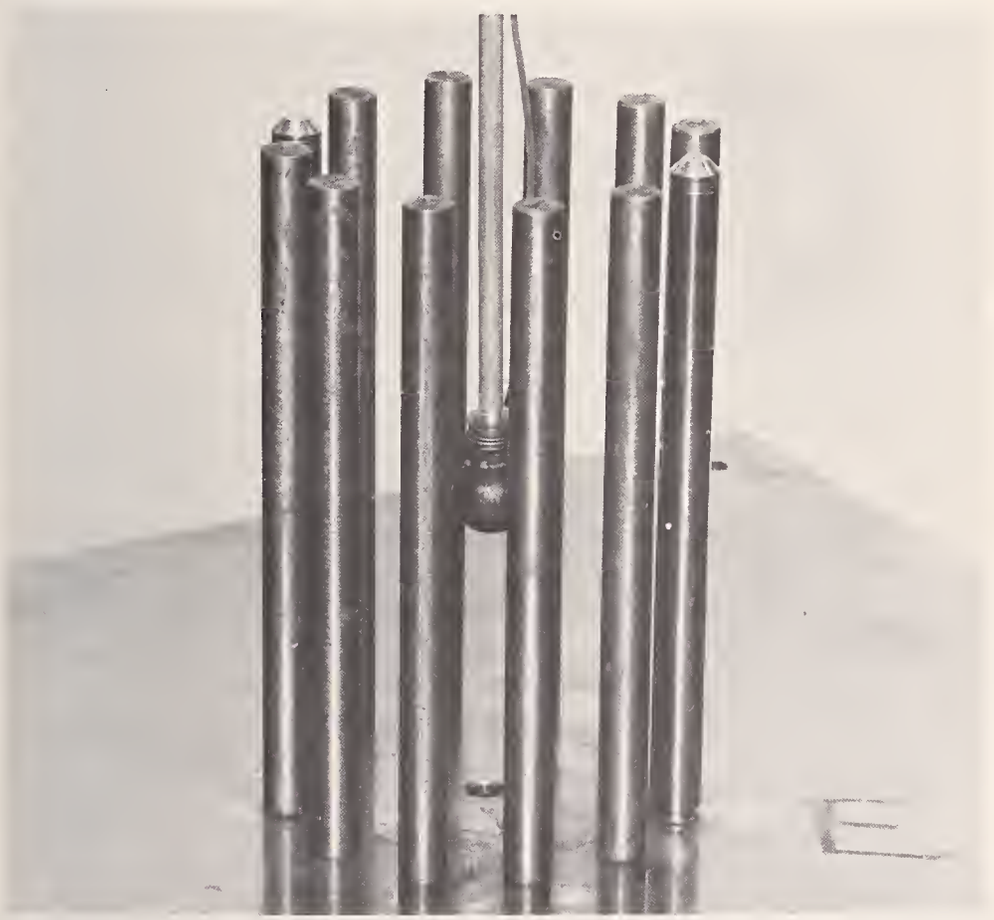
Scattered Spectrum of Water-Shielded Sources. Measurements have been made to determine the gamma-ray spectra produced by the Bureau's two water-shielded cobalt 60 radiation sources. A demountable model was constructed having separate radioactive parts in the form of thin wires. A series of ion chamber measurements made with the model in different stages of assembly gave the scattered intensity contributed by the various component parts and by the water. The scattered intensity was found to be 21 percent of the total, and the spectral distribution approximately the same as that of singly scattered primary photons. This information, permitting more accurate estimates of absorbed dose delivered by these sources, will make feasible an experimental comparison of calorimetric and ionization methods of radiation dosimetry.

Standards of Radioactivity. In the past year the sum of standards sold and calibrations performed exceeded 600; several international camparisons have been carried out; at least two new methods of measurement have been developed; and a material contribution has been made to the development of the radiation standards laboratory of the Bureau International des Poids et Mesures by sending a staff member to work at Sevres for six months. An iodine 125 solution standard and a cerium 139 gamma-ray point-source standard have been developed and a new series of krypton 85 standards has been issued. Intensive investigation of the accuracy of mass-spectrometric analyses of carbon 14 in carbon dioxide, carried out in conjunction with the Applied Analytical Research Laboratory, resulted in the NBS value of the half life of carbon 14 being reduced 15 years to 5745 $\pm$50 years, a change which is less than one-third of the estimated probable error. This determination brings the NBS value into close agreement with the

Cambridge average of British, Swedish, and United States results, adopted in July 1962, of 5730 ±40 years.

The two new methods of measurement which are of note are (1) the use of silicon at temperatures below 4.2 °K for the detection of beta particles, and (2) the use of Auger electrons to indicate the source self-absorption for X-rays in the preparation of standards of the electron-capturing nuclide iron 55.

The low-level radioactivity program has made considerable progress, and intercomparative measurements have been satisfactorily carried out on samples of strontium-yttrium 90 and iodine 131 in water distributed by the U.S. Public Health Service, and of iodine 131 in evaporated milk distributed by the U.N. International Atomic Energy Agency. A new method has been developed for the quantitative analysis of low levels of uranium in water and in urine by ion exchange without lengthy preparation, thereby reducing the time required for a measurement from four to two days.



Model used to determine the gamma-ray spectra of the Bureau's two water-shielded cobalt-60 radiation sources. Pencils with tapered ends contain radioactive material; flat-ended pencils are solid dummies. Cavity ionization chamber in center of model measures intensity of radiation. **(See p. 80.)**

Radiation Interaction With Matter. Investigations have been made of some of the important processes involved in the interaction of electrons with matter in the energy region from 50 to 500 kev. These processes include electron single scattering with and without atomic excitation. The experimental studies were carried out with the NBS 500-kev electron accelerator and with magnetic and scintillation spectrometers. The experimental results show good agreement with available theoretical predictions for the process of scattering without atomic excitation. However, for the process of scattering with atomic excitation, there are large discrepancies between experiment and theory which are attributed to the approximations used in the available theory.

Radiation Interaction with Nuclei

The Interaction of Bremsstrahlung with Alined Nuclei. During the last five years, a series of experiments has been carried out to study the interaction of high-energy photons with nuclei known to have large intrinsic deformations (i.e., nuclei with large intrinsic quadruple moments). Studies were made of both the scattering and the absorption of photons by these nuclei. The analysis of these data indicated such nuclei probably have a large intrinsic tensor polarizability. During the last year and one-half, this part of the polarizability of the holmium nucleus has been studied directly in an experiment designed to show that the nuclear absorption cross section in the giant resonance energy region depends upon the orientation of the nucleus with respect to the photon beam. The experiment has been carried out in collaboration with a group from the Low Temperature Laboratory. Holmium nuclei are alined along the c-axis of a single crystal of holmium ethyl sulfate by the Bleaney method. The crystal, cooled to 0.03 °K by means of a continuously operating He^3 refrigerator, can be rotated with respect to the beam from the betatron.

The experiment consists of measuring the yield of photoneutrons from the holmium ethyl sulfate crystal as a function of the orientation of the crystal's c-axis with respect to the photon beam. This is done at a series of six betatron operating energies between 10 and 20 Mev. At temperatures above 4.2 °K, only slight asymmetries are observed in the yield of photoneutrons as the crystal is rotated. To a large extent these can be accounted for by the slight geometrical asymmetry of the crystal. At 0.3 °K, considerably larger asymmetries are observed that can be attributed to the tensor polarizability of the holmium nucleus.

Nuclear Matter Distributions as Determined from Neutral Meson Photoproduction. The major process contributing to neutural meson photoproduction near threshold leaves the residual nucleus in its ground state. Thus, the process is completely coherent and exhibits strong nuclear size effects. In the Born approximation, these nuclear size effects can be represented by a form factor. The form factor for π° photoproduction is the same as that for elastic electron scattering, neglecting nucleon size, except that the electron scattering experiments observe the distribution of electric charge in the nucleus, whereas the π° photoproduction observes both protons and neutrons

Holmium ethyl sulfate crystal used to measure the dependence of the yield of photoneutrons from holmium on the orientation of the nucleus with respect to the photon beam direction. Nuclei were alined by cooling the crystal to 0.29 ° K. **(See p. 82.)**

with equal weight and is thus a measure of the nucleon matter distribution.

By comparing the results of electron scattering and π° experiments, it may be possible to determine information about the relative distributions of protons and neutrons in the nucleus.

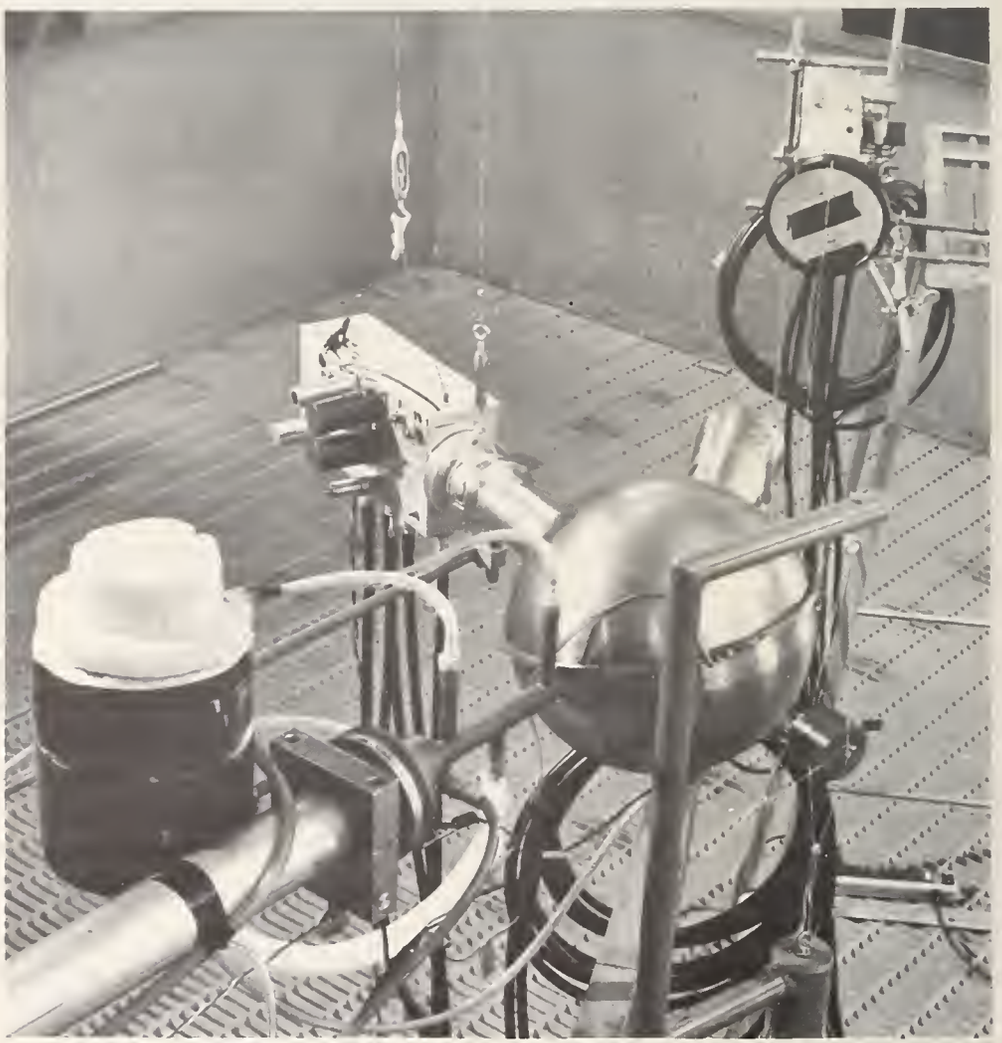
During the last several years, a series of measurements has been made of the photoproduction of π° mesons from complex nuclei. The results of measurements on elements carbon, aluminum, copper, cadmium, and lead have indicated nuclear rms radii agreeing within the errors with those deduced from electron scattering experiments. The rms radii are determined to within 2×10^{-14} cm.

A series of measurements are currently in progress to study π° photoproduction from the elements carbon, magnesium, aluminum, silicon, and sulfur to improve the absolute accuracy of the measurements and to compare the radii of neighboring nuclei. In addition, aluminum with a spin of 5/2 should be a very good element with which to investigate the possibility of spin-dependent contributions to the π° photoproduction. Preliminary analysis of data indicates that the elastic photoproduction process does not seem to be dependent on the spin of the target nucleus. The data for aluminum are not different (except for size effects) from the data obtained from magnesium and sulfur, both of which have a major isotopic abundance of spin zero. A rough fitting of the data from magnesium, aluminum, and sulfur indicates that the ratio of the nuclear matter distribution to the electric charge distribution is constant to within the probable error of 2 percent.

An attempt is being made to obtain a sample of O^{18} water to make similar measurements. This should be an especially interesting case since O^{18} con-

sists of a closed O^{16} shell with two *d*-wave neutrons outside the closed shell.

Neutron Time-of-Flight Technique. Measurements of the interaction of high-energy neutrons with nuclei are useful both for investigation of the parameters of nuclear models and for calculation of the shielding characteristics of bulk matter. An experiment has been performed to measure the elastic and inelastic scattering cross sections, as a function of scattering angle, of 14-Mev neutrons on calcium. The experimental technique utilizes measurement of the flight times of the scattered neutrons to determine their energies; groups of neutrons having flight time differences as small as 1.5×10^{-9} sec have been resolved. Theoretical calculations of the elastic cross sections have also been carried out, using the optical model of the nucleus, for a wide range of neutron energies. The experimental results for calcium agree with the general predictions of the theory, but have also confirmed small discrepancies previously reported.



The target area for measurement of the scattering of 14-Mev neutrons. The neutrons are produced on a target at the center of the thin-walled sphere. The counter at left center records the time at which a neutron leaves the target, and the counter at the right rear detects this neutron after it has scattered from the small cylindrical scatterer in the right foreground. **(See p. 84.)**

Previous Bureau investigations using γ-rays have demonstrated the large deformation of the holmium nucleus. The neutron time-of-flight equipment that has been developed will permit further investigation of this deformation using 14-Mev neutron scattering from alined holmium nuclei.

Particle Interaction Theory. More than 30 elementary particles and resonances have been found. The classification and correlation of the properties of these particles—masses, spins, parities, moments, and decay widths—are among the most challenging problems of modern physics. Interestingly enough, the methodology used in attacking this problem of elementary particle spectroscopy is quite analogous to the now familiar techniques of nuclear and optical spectroscopy.

The introduction of unitary symmetry (SU3) in the octet model or "eightfold way" to describe the strong interactions between elementary particles has recently been proposed and its consequences are now being explored. Unitary symmetry is a generalization of isospin symmetry which also includes the strangeness quantum number. In the octet model, the spin$=\frac{1}{2}$ baryon, i.e., the neutron, proton, Σ^-, Σ°, Σ^+, Ξ^-, Ξ°, and Λ particles are considered as members of a unitary multiplet just as the neutron and proton are the two members of an isospin multiplet. Similarly, the pseudoscalar mesons, K°, K^+, π^-, π°, π^+, η, K^-, $\overline{K}^\circ$ are also members of a unitary multiplet.

Particular attention has been paid to the formulation of possible tests of the theory by examining reactions of the type

$$\text{meson} + \text{baryon} \rightarrow \text{baryon resonance} + \text{meson}$$

and

$$\text{meson} + \text{baryon} \rightarrow \text{baryon resonance} + \text{vector meson.}$$

The role of the gamma-ray in the eightfold way has also been investigated in detail. Quantitative predictions about processes like the photoproduction of baryon resonances and their electromagnetic decays have been formulated.

Preparations for New Linear Accelerator. Progress continues in the design and construction of the NBS linear accelerator (Linac). Tests of the first prototype accelerator section are complete and have been valuable in fixing the final production phases of the new machine. Completion of the accelerator is expected in the fall of 1963 and installation in the new laboratory at Gaithersburg, Md., in the spring of 1964. Research with the accelerator will meet the increasing need for basic data and physical measurement technique developments in the use of intense high-energy electron beams in radiography, radiology, nuclear physics research, and radiation processing of materials.

Linear Accelerator Theory. Existing theories of linear accelerator performance have always assumed that the Linac waveguide is a broadband device without dispersive properties. In reality the Linac waveguide is highly dispersive and has a passband only a few megacycles wide. Substantial fluctuations in th rf power transmitted by the waveguide of the prototype of

the NBS accelerator have led to the development of Linac theory to include these dispersive effects, and theoretical calculations successfully predict the observed fluctuations. The theory has been extended to include dispersive effects in the heavily beam-loaded Linac, and a number of new predictions have been made concerning Linac behavior. These predictions are of considerable importance to many linear accelerators being considered at the present time. Similar calculations have been made of waveguides being considered for the very large linear accelerator being constructed at Stanford University. When the NBS linear accelerator is available, an attempt will be made to confirm other interesting predictions of these calculations.

Heavy-Ion Source for Magnet-Optic Studies. A 400-kev krypton ion source has been developed to study the detailed performance of beam deflecting magnets and of magnetic spectrometers. Since a 400-kev krypton ion has the same momentum as a 250-Mev electron, this will allow detailed study of magnets over the range of interest on the NBS Linac.

The present performance of the ion source is sufficient for detailed study and ray tracing of individual magnets. Further refinements will be necessary before it can be used to test entire magnet systems where the total flight path in the system approaches 150 feet.

The first bending magnet of the NBS beam-handling system has been delivered and measurements of the deflecting properties of this magnet are being made.

High-Current Beam-Handling Problems. The very high beam current of the NBS Linac poses unique and severe problems of metal fatigue and heat dissipation in collimating and stopping the beam. A number of measurements have been made in collaboration with High Voltage Engineering Corporation and Yale University on these problems, using the Yale Linac. The results of these measurements have demonstrated the extreme importance of the pulsed nature of the Linac beam on metal fatigue and on cooling behavior and have led to design information which will be used in developing the NBS beam-handling system.

Equipment for Use With Linac. The current effort in the Linac research program is to develop major long-lead-time pieces of experimental equipment. It is hoped to have this equipment developed and on hand at the time the Linac is available. The major items being developed are (1) a magnetic spectrometer for performing elastic and inelastic electron-scattering experiments, (2) a magnetic spectrometer for detecting heavy charged particles, protons, deuterons, alphas, etc., (3) equipment for producing beams of positrons and monoenergetic photons, (4) facilities and equipment for studying (γ, n) reactions using nanosecond time-of-flight techniques, and (5) equipment and techniques for accurate and convenient electron beam monitoring.

Data-Logging and Data-Handling System for the Linear Accelerator. A detailed examination has been made of the needs for data-logging and data-processing equipment for the experimental programs using the linear accelerator. This survey has indicated that there are major scientific, tech-

nical, and economic advantages to the use of a small on-line, general-purpose computer for these data-logging problems.

As there exist satisfactory commercial computers for these applications, the major problems are the development of various types of input and display equipment and program organization of the computer.

An examination of the experiments which would use this system reveals that a complete data-logging program can be accomplished by the use of one or more of a small number of basic building-block input subsystems. The logical design of these subsystems and detailed circuit drawings are nearly completed. Hardware to construct a portion of the input system is ordered and construction began in July 1963.

The computer chosen for this system, SD–920, is on order and delivery is expected in September 1963.

Considerable effort is now going into an investigation of the coding and programming problems which will occur with simultaneous usage of this system by several experimental groups and in procedures for rapid and convenient program control to meet the variable and uncertain needs of experiments. While these are not easy problems satisfactory solutions seem to be feasible.

It is hoped that this data-logging system will be in useful operation on experiments in approximately one year.

2.1.8. LABORATORY ASTROPHYSICS

The Joint Institute for Laboratory Astrophysics (JILA), established in April 1962 on the University campus at Boulder, Colo., is a collaborative effort of the Bureau and the University of Colorado. The Institute provides a center for both research and advanced training in areas of physics and astrophysics which provide the scientific basis for meaningful measurement in very hot gases. Here, scholars in many specialties are given the opportunity to exchange ideas and data. The staff is composed of appointees of both the Bureau and the University of Colorado.

Astrophysics is the application of physics to problems of astronomy. At JILA, theoretical rather than experimental work is emphasized, with greatest effort concentrated in those areas of theoretical astrophysics which provide the physical understanding for fundamental processes in stellar atmospheres. This effort is closely related to low-energy physics.

In atomic physics, heaviest emphasis was placed on atomic, electronic, and ionic collision processes. Also studied were optical resonance phenomena and lasers, ultraviolet and visible atomic spectroscopy, and continuous absorption coefficients of ions, and ionic mobilities.

In astrophysics, data from the 1962 solar eclipse were analysed, and work on solar flares was continued. Theoretical techniques to describe departures from local thermodynamic equilibrium of a gaseous atmosphere are under development. Attempts are underway to determine helium abundance in the solar chromosphere and the chromospheric structure of certain types of stars.

Physics of Atomic Collisions. The mobilities and diffusion coefficients of three species of helium ion were measured with high precision, and the rate coefficient for the formation of helium molecular ions in three-body collisions was also determined. This work is particularly interesting because it appears to conflict with conventional theoretical limits on the molecular helium mobility. Similar measurements were made in neon. Experiments being planned include photodetachment of negative ions of molecular oxygen under conditions of thermal equilibrium at room temperature.

With AEC support, a detailed experimental study of dissociative ionization of hydrogen molecules by electron impact was completed. Specifically, the kinetic energy distribution of protons from the dissociating ions was measured and—for the first time—agreement obtained with theoretical prediction. More importantly, the angular distribution of the protons was determined with respect to the ionizing electron beam direction, and this distribution was shown to be highly anisotropic, as predicted. This result proves that most of the values of cross sections for collisions of dissociating molecules reported in the literature should not be considered correct, since the geometries of these experiments usually were predicted on the assumption of isotropy. Studies on angular distributions in oxygen and nitrogen are continuing.

The photodissociation of the positive ion of molecular hydrogen is being studied in a cross-beam experiment also supported by AEC. The integrated cross section appears, in general, consistent with theoretical expectation, although the spectral distribution of the cross section may be anomalous.

An experimental study of the elastic scattering of monoenergetic electrons from atomic hydrogen in crossed beams is in progress.

Analysis of data taken earlier on the photodetachment cross section of the negative iodine ion was completed with financial support from ARPA-ONR and in collaboration with the Atomic Physics Division with the result that the binding energy of this ion is now known to an accuracy of 3 mv. In addition, comparison with shock-tube data of other experiments provides insight into the unusually small depression of negative-ion binding energies in dense plasmas. Concurrently, theory for the threshold behavior of negative ion photodetachment, including the effects of polarization, is being developed by one of the JILA Visiting Scientists with a stipend from the University of Colorado's NSF Grant. The experiments on the negative iodine ion will provide a critical test of the theory when the effects of the iodine quadruple moment have been included in the theory.

The most accurate cross-section calculation for the negative hydrogen ion bound-free absorption coefficient yet determined theoretically was completed, and it is in excellent agreement (within a few percent) with the results of precise experiments. Meanwhile the Bureau is assisted in this effort by a CU contract from AF Special Weapons Center involving detailed calculations of the free-free absorption coefficient which are being made using these accurate wave functions. A new calculation of the cross section for ionization of the negative hydrogen ion by electron impact shows

that the previous result was too large. An attempt to measure this cross section is planned.

Also in progress by JILA Visiting Scientists are a calculation of the cross section for ionization of atomic hydrogen by proton impact and a study of the ionization of Fe XIV by electron impact.

This two-quantum photodetachment probability for negative iodine and other ions was calculated. A giant-pulse ruby laser makes possible an experimental measurement of this probability using the photodetachment apparatus.

Astrophysics. Work continued on the development of theoretical techniques for describing a gaseous atmosphere, departing from local thermodynamic equilibrium, in which aerodynamic phenomena provide an energy source but are too small to provide a momentum source. An attempt was made to extend this work to treat the solar corona and the rocket ultraviolet spectrum of the sun.

The chromospheric spectra from the very successful 1962 Solar Eclipse Expedition to New Guinea were analyzed in collaboration with astrophysicists from the High Altitude Observatory at Boulder, Colo., and the Sacramento Peak Observatory at Sunspot, N. Mex. A serious discrepancy in the literature concerning the temperature of solar prominences has been explained.

Two other investigations are nearly complete: a study of the excitation of helium lines in the solar chromosphere leading to a determination of the helium abundance, and a study of proton kinetic energy distributions in coronal-loop solar prominences.

A set of observations of line profiles of the calcium *H* and *K* lines in spectra of *G*, *K*, and *M*-type stars were completed at Mt. Wilson Observatory near Pasadena, Calif., in collaboration with the UCLA Department of Astronomy. These data will be interpreted in an attempt to discern the chromospheric structure of such stars.

Work on solar flares was continued by a JILA Visiting Scientist (NSF). An analysis of the spectrum of the September 2, 1960 flare was completed, and some of the 1962 eclipse data were reduced.

An unusual photoelectric instrument was developed for measuring the relative strength of solar chromospheric continua on both sides of the Balmer discontinuity. The equipment was used in Alaska during the July 20, 1963 solar eclipse.

Resonance Physics. The possibility that optical pumping by sunlight occurs naturally in the sodium of the earth's upper atmosphere was investigated with the result that the effect appears negligible except in the case of artificial sodium releases from rockets at higher altitudes. A theoretical investigation was made of hydrogen atom spin exchange collisions, with applications to the operation of a hydrogen maser. Optical pumping of rubidium vapor in the presence of a high-pressure buffer gas was observed experimentally using natural sunlight.

A giant-pulse ruby laser, producing about 1 joule and up to 50 Mw of monochromatic light, was developed for the purpose of studying nonlinear interactions of atoms and matter with radiation. The feasibility of measuring the two-quantum photodetachment of negative iodine ions has been studied. A fluorescence experiment on anthracene has been carried out in collaboration with the Radio Standards Laboratory, in which two photon processes give a fast fluorescence as well as the previously observed delayed fluorescence due to exciton-excitor collisional recombinations. Preliminary work on detection of high-frequency beats from two closely spaced gas laser lines in the infrared was started.

Work was begun on an apparatus to measure the acceleration of gravity using an interferometer (one plate of which is the falling object) together with a gas laser light source. In addition to the importance of this measurement to the field of standards, possible variations in the gravitational field strength (which could be of cosmological origin) might be detected with the high precision obtainable with this new technique.

Plasma Physics, Statistical Physics, and Aerodynamics. An experimental study was made of the structure of self-ionizing hydromagnetic shock waves in a magnetic field. Experiments are planned to apply hydromagnetic shocks to the study of solar flares.

Data Center on Atomic Collision Cross Sections. The Data Center completed its survey of all literature reporting cross sections for two-body collisions involving a free electron, and is currently providing bibliographic searches for the general scientific community. The material is coded by subject matter as well as by normal reference to author, journal, etc. Preparation for the publication of the complete bibliography by subject classification is in progress. The Data Center has been jointly financed by ARPA, ONR, and NBS.

2.2. CHEMISTRY AND PROPERTIES OF MATERIALS

2.2.1. ANALYTICAL AND INORGANIC CHEMISTRY

Recent scientific and technological advances require new, accurate data on the properties of materials. To help fill this need, the Bureau conducts intensive investigations to determine the physical and chemical properties of both common and rare elements and compounds. Such investigations require new and improved analytical techniques as well as tried and proved methods. New instrumental analyses hold promise for improved analytical speed, accuracy, and precision.

Consultant services are available to Government and industry alike on diverse subjects such as radioactivity (the Bureau participates in the Atomic Energy Commission's standards program), the compilation of scientific and technical data, the measurement of physical constants and chemical properties of materials, and the preparation of standard samples. The Bureau also

issues standard materials of known composition for metallic and nonmetallic inorganic compounds as well as standards of composition for some organic materials.

New activities include a study of inorganic synthesis and reaction rates, an analysis of trace impurities and their effect on the properties of materials, the preparation of standards required for determining atomic weights by isotopic abundance measurements, and a study of optical and X-ray spectra in crystals at low temperatures.

Atomic Weight Redetermination. Atomic weights of several elements are being redetermined with increased accuracy by employing mass spectrometric methods of comparing natural materials with reference standards prepared from concentrates of individual isotopes. Extracting a given element from a wide variety of natural sources in order to establish a normal value for its atomic weight is an important part of the program. The work of redetermining the atomic weight of copper is nearly complete, and preliminary work for redetermining the atomic weights of other elements, especially bromine, is now in progress.

Reactivity of Coordination Compounds. Studies of coordination compounds are being conducted to determine the role of these substances as catalysts and reaction intermediates, and to investigate their application to the synthesis of new compounds. As part of these studies, isotopically enriched boron compounds are employed to study the displacement of one such compound from a complex by another compound. In addition to providing information about the reactivity of boron coordination compounds, these studies suggest several possibilities for solving problems of synthesis in boron chemistry.

Thermodynamics of Aqueous Solutions. Studies of thermodynamic constants of acids, bases, and salts and their interactions in solution provide basic knowledge essential for improving and extending existing methods of measurement. A new technique, isopiestic vapor-pressure measurements, when applied to a water-urea-sodium chloride system yields free energies or chemical potentials of each of the three components at all compositions up to saturation; that is, up to about 47 percent urea and 14 percent sodium chloride. From the free energies obtained, the effect of added urea on the solubility of sodium chloride and the effect of added sodium chloride on the solubility of urea can be calculated. The composition of the solution at the point of mutual saturation (where the solution is saturated with respect to both urea and sodium chloride) is then readily derived.

p*H *Scale for Alcohol-Water Solvents. Because of its reproducibility, determining the *p*H of alcohol-water solutions found with commercial electrometric *p*H equipment is an important control variable in many industrial and research operations. Determined in the conventional way, *p*H numbers are interpreted in terms of hydrogen ion concentration or activity only when the solvent medium is pure water. A scale of *p*H (designated *p*H*) for methanol-water and ethanol-water media has been proposed, its practicability has been demonstrated, and procedures for assigning standard *p*H*

values to refcrence solutions have been devised. The *p*H* determined experimentally bears a simple relation to dissociation constants and other thermodynamic quantities in the samc medium and, as such, should have wide application in many branches of chemistry and biology. Furthermore, scales of *p*H* can bc established for many other solvent systems by similar procedures.

Dielectric Cryometry for Determining Purity. The purity of a compound can be determined by measuring the temperatures corresponding to particular solid-liquid ratios while the compound melts or freezes. In a method called dielectric cryometry recently investigated by the Bureau, the solid-liquid ratio is determined by measuring the change in dielectric cofficient, and by simultaneously measuring corresponding temperatures during the melting process. The data collected indicate a change in an intensive property of the material, and samples of only 4 to 10 milliliters are required. Purity measurements, made on a number of compounds with diverse dipole moments and polarizabilities, resulted in a precision of 0.005 to 0.0004 mole percent. Refinements in the design of the apparatus may increase the precision still further.

Argon Shielding in Spectrochemical Analysis. Spectrochemical analysis of high-temperature alloys is difficult because given elements volatilize at different rates depending on whether they are present in an iron-, nickel-, or cobalt-base alloy. Standards for the same element in all three

Isopiestic vapor pressure measurements provide a new technique for measuring the thermodynamic properties of aqueous solutions containing one electrolyte and one non-electrolyte. The wire apparatus is used to close the covers on the sample cups while they are still under vacuum in the dessicator. **(See p. 91.)**

Laser microprobe can perform a spectrographic analysis of a sample as small as 50 microns in diameter. **(See p. 93.)**

types of matrix are therefore necessary. Shielding the specimens with argon gas reduces the differences in volatilization rate and shows promise of reducing the number of spectrochemical standards needed for the routine determination of the major constituents in high-temperature alloys.

Transition Probabilities. Transition probabilities are important to analytical chemistry and basic spectroscopic research. Most transition probabilities determined to date have been for gaseous elements that are easily introduced into an arc discharge. However, through exhaustive studies of the properties of the gas-stablized arc, data for 105 lines in the spectrum of neutral atomic iron have been redetermined. An analysis of the new data has resulted in transition probabilities for neutral atomic iron more precise than those obtained in three earlier investigations.

Laser Microprobe. A prototype of a commercial laser microprobe is being investigated and, with certain changes, is expected to be a useful tool in microanalysis. The instrument permits spectrographic analysis of samples as small as 50 microns in diameter. A brief, high-energy pulse

of light from a ruby laser, focused through a microscope onto the spot to be analyzed, is sufficient to volatilize the sample as a jet of vapor. This vapor jet, passing through a gap between two graphite electrodes connected to a large condenser, triggers a spark discharge which excites the elements in the sample. The spectra characteristic of the light from the spark discharge are recorded with a spectrograph in the usual way. Almost all the elements in the periodic system may be excited simultaneously. In addition to its application to the analysis of small samples, segregates, and inclusions, the laser microprobe is expected to be valuable for studying high-purity materials. An advantage of the device is that it requires little or no preparation of the sample prior to the analysis.

Solvent Effects on the Rates of Acid-Catalyzed Reactions. The speed of chemical reactions in solutions is influenced by the nature of the solvent, particularly when an acid or base takes part. For example, the rate of a reaction, catalyzed by acid, may change because of the effect the solvent produces on the acidity of the medium or because the free energy of activation is altered. The rate of hydrolysis of acetal, a typical acid-catalyzed reaction, was studied in solvents prepared by mixing water with varying proportions of acetone, dimethylsulfoxide, dimethylformamide, or *N*-methylpropionamide. Replacement of half of the water by acetone caused the rate to fall to $\frac{1}{15}$ its value in pure water; and similar amounts of dimethylsulfoxide, dimethylformamide, and *N*-methylpropionamide reduced the rate to $\frac{1}{40}$, $\frac{1}{55}$, and $\frac{1}{300}$, respectively. The mechanism of the solvent effect is still not clear, but the change in rate does not appear to be linked closely with the change of either the dielectric constant or basicity of the medium.

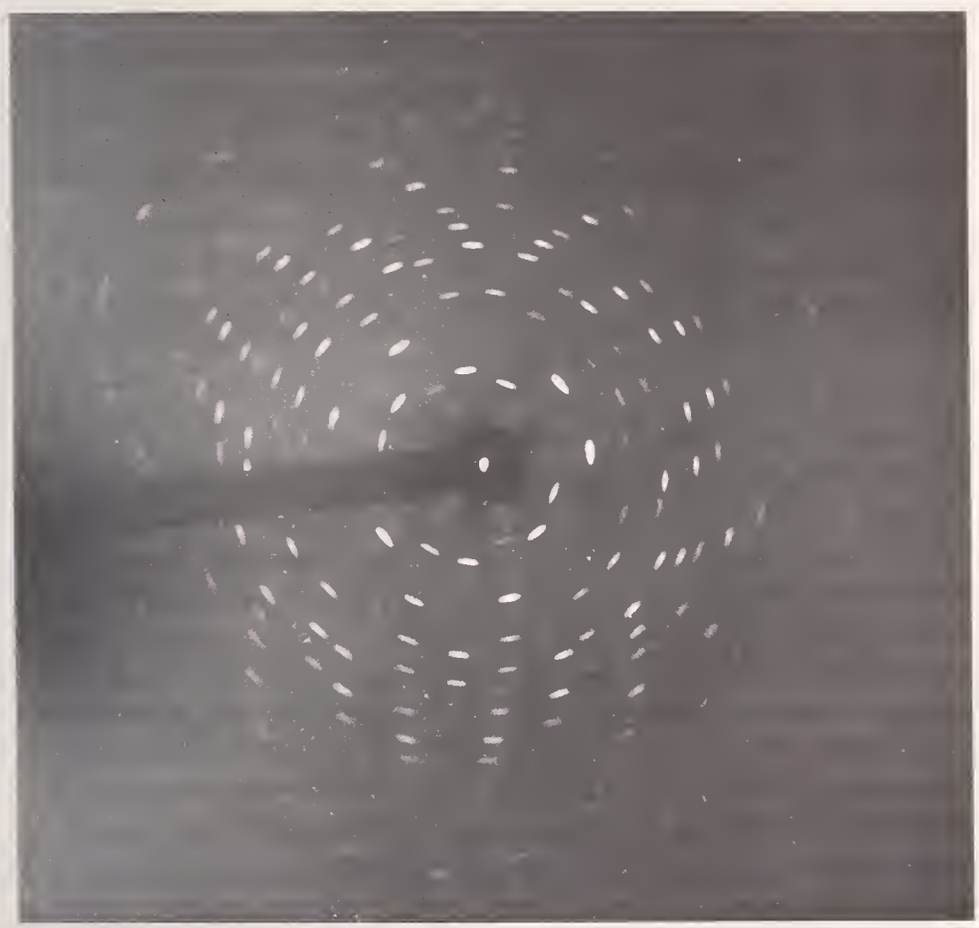
Acidities of Dinitrophenols in Benzene and Water. Quantitative comparisons of the behavior of acids and bases in two dissimilar solvents like benzene and water furnish valuable insight into the mechanism through which solvents affect chemical reactivity. Six dinitrophenols, all having the same composition but differing in atomic arrangement, have ionization constants in water ranging from approximately 10^{-4} to 10^{-7}, as shown by careful spectrophotometric measurements of the acid strength. However, the relative order of acidic strengths in benezene differs from that in water. Information of this type is helpful in interpreting the behavior of dinitrophenols in nonaqueous solvents, where they are finding increased use as reference acids.

Crystal Growth From Mixed Solvents. Solvent effects on the growth of large crystals from solution have recently been illustrated in experiments with oxalic acid. For example, anhydrous oxalic acid crystallizing from glacial acetic acid solution gives inferior single crystals containing inclusions of the mother liquor. However, the addition of small amounts of water added to the solvent produces single crystals of greatly improved quality, and nucleation is inhibited. A phase study of the system oxalic acid–acetic acid–water at 50 °C showed that anhydrous oxalic acid is the stable solid phase in equilibrium with aqueous acetic acid solutions containing up to

5.2 percent water. In other experiments, single crystals of oxalic acid dihydrate, difficult to grow from water solution, were of good quality when grown in acetone-water mixtures.

Studies of Crystal Symmetry. A general study on the effect of homogeneous strain on crystal symmetry has shed light on the problems of internal friction due to point defects, second-order piezoelectric coefficient, second-order transformations, solid solution effects, and crystal field phenomena; and has suggested procedures for space-group determinations from ambiguous X-ray patterns. The treatment is general and applies to all crystalline solids with any type of strain.

X-Ray Analysis of Crystalline Solids. A high-voltage (150-kv), fine-focus X-ray apparatus with a special collimating slit has been procured to obtain X-ray diffraction diagrams of single crystals up to 1 in. thick. Conventional diffraction procedures can be applied only to thin crystals or to surface layers of specimens. The X-ray unit has also been used to obtain diffraction patterns of single crystals enclosed by protective containers of Pyrex glass.



X-ray diffraction pattern of germanium single crystal obtained with high-voltage fine-focus X-ray unit. This special equipment can be used to explore single crystals up to 1 inch thick. **(See p. 95.)**

Control of Fractional Distillation. Variations in ambient temperature, barometric pressure, and line voltage affect the efficiency of fractional distillation in the laboratory, principally because these variations cause changes in the flow rate of vapor from the still pot to the column. An automatic controller, consisting of a thermistor sensing device in the vapor line, automatically regulates the heat input to the still pot, thus maintaining a constant flow of vapor to the column. With the use of this device, the fractionation process can operate at an appreciably higher, uniform efficiency throughout the distillation.

Moisture Determination. A gas chromatographic method was developed for determining water content in various materials, particularly in grain. A solution formed by extracting the moisture from the material with methanol is injected into a commercial gas chromatograph. Methanol and water curves are recorded on a strip chart by the gas chromatograph and the relative areas under the methanol and water peaks are used to calculate the moisture content. The method is precise and accurate to 7 parts in one thousand, corresponding to an accuracy better than 0.1 percent of the water content of a typical grain containing about 14 percent moisture.

2.2.2. PHYSICAL CHEMISTRY

The Bureau conducts a broad program of basic research in physical chemistry. The primary objective of this program is the development of an understanding of the molecular basis for macroscopic properties and processes. Particular emphasis is placed on (1) the analysis of relatively complex reactions into elementary molecular processes, (2) the development of the energetics of simple chemical reactions, and (3) the determination of accurate structural parameters of reactive molecular species. Research is conducted in such areas as the kinetics of very fast reactions at high temperatures, the photosynthesis of labeled organic molecules, the structure of reactive molecules which are stabilized in inert matrices at cryogenic temperatures, the interaction of high-energy radiation with organic molecules, the determination of absolute isotope abundancies, the fundamental processes related to surface catalysis, the structure and stability of short-lived species occurring in high-temperature combustion processes, and reaction mechanisms in synthetic organic chemistry. Supporting theoretical studies are made in the general fields of relaxation and transport phenomena, mechanisms of excitation and deactivation of simple molecules, energy distribution in and dissociation of excited organic molecules, and molecular orbital calculation. Considerable effort is directed to the development of special instrumentation and associated techniques of measurement.

The need for critically evaluated fundamental data continually increases at an accelerated rate. During the year a new project was initiated with the objective of developing a simple system for collecting, coding, retrieving, and assessing basic data in selected areas of physical chemistry. This project represents an initial phase in the establishment of a special data-processing activity at the Bureau.

Thermochemistry. During the past year the Thermodynamic Data Group commenced a full-scale revision of NBS Circular 500, *Selected Values of Chemical Thermodynamic Properties,* which contains best values of the heats and free energies of formation of inorganic substances and some organic compounds for which data were available at the time of publication (1952). The current revision will take into consideration all available data through 1961. This program on compilation of standard reference data in the area of chemical thermodynamics has been a continuing part of the Bureau's activities since 1940, with assistance from the Office of Naval Research and the Atomic Energy Commission.

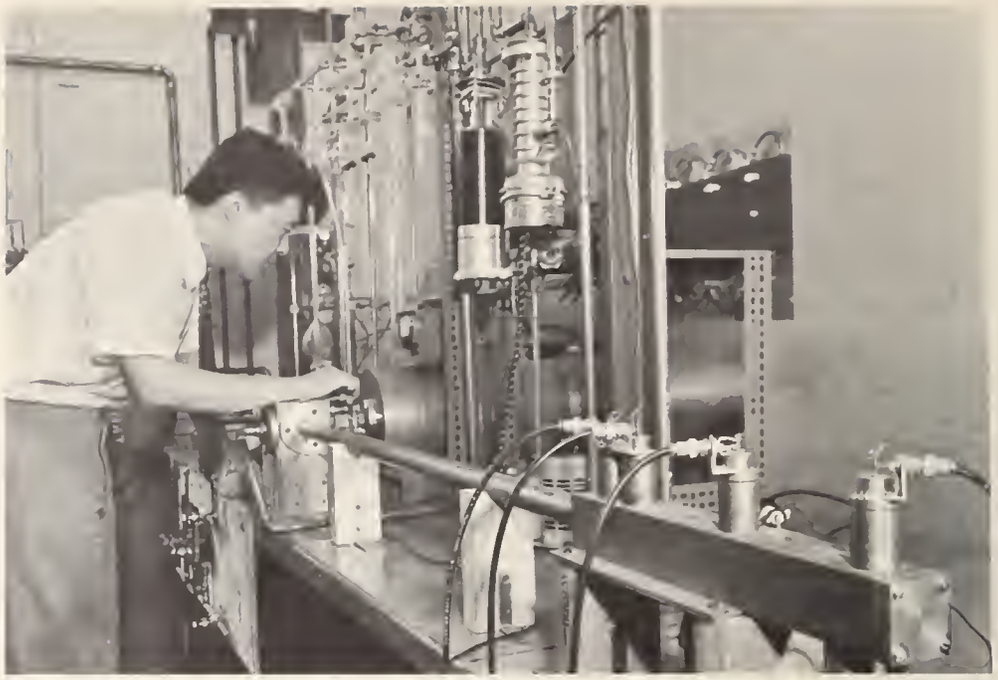
Recent experimental developments have been in connection with the design and construction of two new high-precision calorimeters. An adiabatic solution calorimeter which has a platinum reaction vessel and which can be operated at temperatures to 100 °C will be used for measurements of the heats of solution of refractory oxides and other relatively insoluble materials. The assembly of this apparatus is complete and preliminary tests will be started soon.

An adiabatic rotating-bomb calorimeter is also under construction. This bomb consists of layers of silver and stainless steel, with an internal liner of platinum. The bomb and jacket have been built, and construction of the mechanism to rotate the jack, bomb, and adiabatic shield is now in progress.

Kinetics of Ion Decomposition. Certain unimolecular ion decomposition processes are readily observable in a magnetic sector mass spectrometer. These include processes whose decomposition rates are of the order of 10^6 sec^{-1}. The occurence of such slow decomposition processes in small polyatomic ions is of considerable theoretical interest. Recently, such processes have been observed in ionized molecules of hydrogen sulfide and completely deuterated methane. The substitution of various hydrogen isotopes produced pronounced effects on the occurrence of such processes. With deuterated methane, substitution of one or more hydrogens for deuterium in the ion completely suppresses decomposition. Another study performed with this mass spectrometric technique has given useful information on the problem of energy equilibration in excited polyatomic ions. It was found that the mode of decomposition of an excited ion was independent of its past history. This result supports the validity of the quasi-equilibrium theory of mass spectra.

Field Emission. Recent field-emission studies on the adsorption of carbon monoxide on tantulum and niobium reveal the complexity of the process. It has been found, for example, that there are at least three binding energy states for chemisorbed carbon monoxide on tantalum, and at least two for carbon monoxide on niobium. In general, the similarity found for the adsorption behavior of carbon monoxide on these two metals is very pronounced. There is no detectable difference between adsorption by niobium in the superconducting as compared to the normal state.

High-Temperature Microwave Spectroscopy. A microwave spectrometer which can be operated at temperatures up to 1000 °C has been



The rapid and homogeneous heating of gas samples by shock waves provides a powerful tool for the study of fast reactions at high temperatures. **(See p. 99.)**

constructed in a program supported by the Advanced Research Projects Agency. This instrument permits the extension of powerful microwave techniques to the identification and structure determinations of molecules and radicals which are present in high-temperature systems. There are numerous problems in high-temperature chemistry for which important information can probably be obtained by this technique. Spectra have been detected and analyzed for such molecules as aluminum monoflouride and aluminum monochloride, which do not exist at room temperature, but which are important constituents, for example, in rocket combustion systems. The microwave spectrum of lithium chloride vapor was also observed for the first time.

Enolization and Isomerization Reactions of Reducing Sugars. Numerous investigations over the past 60 years have shown that reducing sugars in alkaline media undergo reversible enolization and that the resulting enediols are intermediates in a variety of rearrangement, elimination, and condensation reactions. The use of recent tracer techniques employing carbon 14 and tritium-labeled sugars makes it possible to follow reaction paths, to measure rates of reaction, and to determine the proportions of products formed.

A broad study of the enolization reactions of the principal pentoses, hexoses, and heptoses is now in progress. Striking differences have been found in the rates at which the various sugars of an epimeric group are formed, and in the effect of various catalysts on both rate and course of the reaction. For example, in rearrangements catalyzed by sodium hydroxide, D-glucose is enolized more rapidly than D-mannose, and the rate of

conversion of D-glucose to D-fructose is five times that of D-mannose to D-fructose. But when pyridine is the catalyst, the rates of enolization are reversed, and the conversion of D-mannose to D-fructose is three times as rapid as that of D-glucose.

Generally, the 1,2-enediol reverts to the corresponding ketose more rapidly than to the epimeric aldoses. The 2-ketoses then yield both 1,2- and 2,3-enediols. Relative rates of 1,2- and 2,3-enolization are being studied by quantitative determination of the rearrangement products of 2-ketoses containing five, six, and seven carbon atoms. Heretofore, unknown 3-keto sugars have been postulated as intermediate in the production of 3,4-enediols. The recent preparation of crystalline D-*manno*-3-heptulose has provided material for direct study of 3,4-enediols. On treatment with alkali, the new compound gave D-*gluco*-2-heptulose, by way of the 2,3-enediol; and, of even greater interest, D-*allo*- and D-*altro*-2-heptulose. Formation of the last two substances requires reversible 3,4-enolization followed by 2,3-enolization.

Cryogenic Surface Chemistry. The reactions of hydrogen atoms with condensed olefins have been under continuing investigation to develop an understanding of chemical reactivity at low temperatures. This research has led to a clarification of several aspects of the chemical and physical processes involved, among which are the establishment of the position of addition of the H atom, the effect of diffusion on the reaction products, and the mechanism of the reaction after the initial step. An important result was the demonstration that, in the H atom addition to the butene at low temperatures, *cis*-butene-2 is not formed. This finding permits a detailed examination of the disproportion atom-recombination reactions of the *s*-butyl radicals, starting with *cis*-butene-2 as reactant.

Kinetic Isotope Effects. A convenient method was developed for measuring isotope effects of tritium in reactions that yield water-*t*. The water-*t* is sublimed and the isotope effect is obtained from the ratio of the molar radioactivity of the sublimed water to that of the initial reactant. This procedure is being applied to the study of a wide variety of organic reactions.

Shock-Wave Studies of Unimolecular Reactions. The rapid and homogeneous heating of gas samples by shock waves gives kineticists a powerful tool for the study of fast reactions at high temperatures. A single-pulse shock tube is being used to study chemical reactions in the temperature range 700 to 1500 °C. In such an instrument the passage of a reflected shock wave heats a gas sample to a high temperature; about a millisecond later, a strong rarefaction wave drastically lowers the temperature, thus quenching the various chemical processes after an accurately known time interval. Conventional analytical methods, such as gas chromatography, may then be used to study the nature and extent of the reactions. Current work is concentrated on studies of simple unimolecular decompositions resulting in stable molecules. It has been possible to extend the range of kinetic studies previously carried out at low temperatures and to impose a critical test on the postulated mechanisms and rate constants. Useful data have been obtained for the *tert*-butyl chloride, bromide, and alcohol decomposition reactions.

Except in the case of alcohol the results confirm those of earlier studies which used quite different methods, and give valuable evidence of the accuracy of the single-pulse shock-tube technique.

Ionization Processes at Surfaces. The studies of ionization on refractory metal surfaces at high temperature have been extended to the measurement of the lifetimes of cesium, rubidium, sodium, and potassium ions on rhenium surfaces as a function of temperature. A general type of potential function with an attractive and repulsive term has been fitted to the data, and trends with size of the positive ion have been determined. The characteristics of the surface ionization process can now be predicted with regard to both ion size and charge.

Polycyclic Ketones. Polycyclic ketones, derived from inositol by oxidation, bridge the gap between the cyclitols and certain biologically important phenols. Because of their reactivity, very few of these important intermediates have been isolated. In a project sponsored by the Division of Air Pollution, Public Health Service, it was found that the residue, after nitric acid oxidation of *myo*-inositol and separation of known products, contained a new substance, shown to be D-L-*xylo*-trihydroxycyclohexenediolic acid. The substance, the enolic form of a diketo inositol, is readily oxidized to a new trihydroxycyclohexanetrione. With basic catalysts, the acetate of the enediolic acid can be aromatized and converted by hydrolysis to pentahydroxybenzene, an important substance not generally available nor closely investigated. This synthesis opens up a promising area for study.

These crystals of D-manno-3-heptulose monohydrate, the first pure crystalline 3-keto sugar to be prepared, will provide Bureau scientists with an opportunity for direct study of this and related sugars. **(See p. 100.)**

Acetylation of the new trione under acidic conditions gave an unexpected tricyclic condensation product, the chemistry of which is being investigated.

Vacuum Ultraviolet Photochemistry. The interaction of vacuum ultraviolet radiation with various molecules is being investigated under extremes of temperature and pressure in order to understand the chemistry of fragments of molecules. The CH_3CH fragment has been found to decompose to give H_2 and acetylene, as well as to rearrange to form ethylene. The effects of energy of the exciting radiation can best be studied in vacuum ultraviolet photochemistry by using pure, intense line sources. Source technology has been advanced by studying emission of rare gas resonance lamps under varying conditions of temperature, pressure, filling gas, and additives.

High-Temperature Surface Reactions. The increasing use of refractory metals in military and civilian technology requires considerable understanding of the physical and chemical behavior of these metals. The high-temperature surface reactions of chlorine and bromine with nickel represents an active area of investigation in which chemical kinetic effects are being studied. A highly successful technique has been developed in which the products of reaction are sampled with a time-of-flight mass spectrometer. The reaction surfaces may be either those of a single crystal or polycrystalline material. The mechanism of the nickel-bromine as well as the nickel-chlorine reaction has been established. In either case, the reactive monohalogen species has been found to be an important product in the higher temperature region. This work is conducted under the sponsorship of the Atomic Energy Commission.

Radiolysis of Simple Hydrocarbons. The gas-phase radiolysis of single hydrocarbons, at pressures up to the critical pressure, was investigated with Atomic Energy Commission support. It was shown that, in all cases, the unimolecular decomposition of parent ions and of electronically excited neutral molecules contributes to the formation of observed products. In the radiolysis of propane at one atmosphere, the primary fragmentation of the parent ion shows a good correspondence to the recently calculated 10^{-10} second breakdown pattern, while the modes of decomposition of the neutral excited molecules are similar to those observed in the vacuum ultraviolet photolysis. It has been firmly established that accurate relative rate constants of ionic reactions occurring at atmospheric pressure can be obtained, so that radiation chemistry can now be considered as complimentary to mass spectrometry in the study of ionic reactions. This has been especially demonstrated by the following studies: (1) Determination of the relative rate constants of hydride ion and proton transfer reactions between ethyl and propyl ions and a number of organic compounds; (2) the study of the reactions of CH_5^+ and H_3^+ with hydrocarbons to form carbonium ions. The latter type of reaction, which has not yet been observed in the mass spectrometer, is of considerable importance in radiation chemistry because such reactions may be expected to occur between a large number of protonated parent molecules and neutral molecules.

Standard Reference Data in Physical Chemistry. An investigation of document retrieval systems which will assist in the review and critical assessment of physico-chemical data is now in progress. A selected library of documents—primarily reprints and reports—is being coded by "descriptors" and accession numbers and filed as a deck of optical coincidence or peek-a-boo cards. At the present time this library amounts to about 3000 documents. No thesaurus of terms has been established, so the number of descriptive terms is currently of the order of 20,000 words, including author's names. The present method of retrieval is manual (light screen and an overlay grid), but a Microcite information retrieval machine, developed by the Basic Instrumentation Laboratory, is being constructed. This system is designed to support a broad program for rapidly collecting and assessing data in the physical sciences. The general approach consists in selecting narrow areas of traditional fields of research, assigning reviewers who are acknowledged authorities in the prescribed fields, and providing the mechanical assistance required for document search and reproduction. Subjects for such critical reviews are selected from the major areas of physico-chemical research; for example, chemical kinetics, mass spectroscopy, transport properties, thermodynamics, molecular spectroscopy, radiation chemistry, and surface processes. The reviews will include sets of critically evaluated data which are internally consistent and which can be regarded as "best" values.

2.2.3. INORGANIC SOLIDS

The demand for nonmetallic inorganic solid materials capable of withstanding extreme environmental conditions constantly increases as scientific and space technology advances. The Bureau provides data, techniques, and reference materials to help solve measurement problems in this field of research. Methods for producing and characterizing metallic oxides, glasses, and inorganic nonmetallic crystals have been investigated and data on the properties of many of these materials have been provided. Significant advances were made during the year in developing techniques for studying the physical properties of crystalline solids over wide ranges of pressure and temperature.

Rare Gas Crystals. A deeper understanding of the mechanisms and problems involved in growing large single crystals for industrial and scientific purposes may be gained by studying simpler substances first. Such crystals are formed from the rare gases argon, krypton, xenon, and neon. In current Bureau experiments, argon and krypton crystals are grown near the triple points of these elements, 84 and 116 °K respectively. These studies correlate crystal size and shape, growth rate, temperature gradient, and degree of supersaturated solution with theory, and show that large rare gas crystals may be prepared and studied with many of the same techniques used at higher temperatures on other substances. For example, etch patterns in polycrystalline argon at 77 °K have been studied to learn about grain growth, recrystallization, and annealing; and have been compared to the

Surface of a thermally etched polycrystal of argon. The rare gases form very simple crystals and so are more readily studied to gain a deeper understanding of the mechanisms and problems involved in growing crystals. Diameter of the field of view is 2 mm. **(See p. 102.)**

same processes in metals, where these phenomena take place at much higher temperatures.

Rare gas crystals are perfectly transparent in a broad spectral range, from the infrared to the ultraviolet. Spectroscopic techniques are employed to show the location of small amounts of impurities within a crystal lattice, how they get there, and how they diffuse. These impurities have large effects on the physical properties of crystals.

Molar Volume of Solid Neon Isotopes. Solid neon, like other rare gas crystals, serves fairly well as a model "simple solid." Of the two more abundant neon isotopes, the lighter has a larger zero-point energy (important in determining thermodynamic properties) and may be expected to have a slightly larger molecular volume than the heavier. X-ray diffraction measurements, recently completed at the Bureau, provide values for the lattice constants of the two isotopes throughout most of the temperature range in which they exist as solids (0 to 25 °K), and show this is to be true. Thermal expansion coefficients have also been computed and used to calculate the Grüneisen constant, which increases slightly in this temperature range.

Crystalline Forms of Bismuth Oxide. Bismuth oxide (Bi_2O_3) is assuming an increasingly important role in the ceramics industry as a constituent of glasses of high refractive index, glazes with excellent bonding capabilities, and ceramic bodies having special nuclear and electronic applications. Various crystalline forms of bismuth oxide are being studied, as well as their reactions with other oxides.

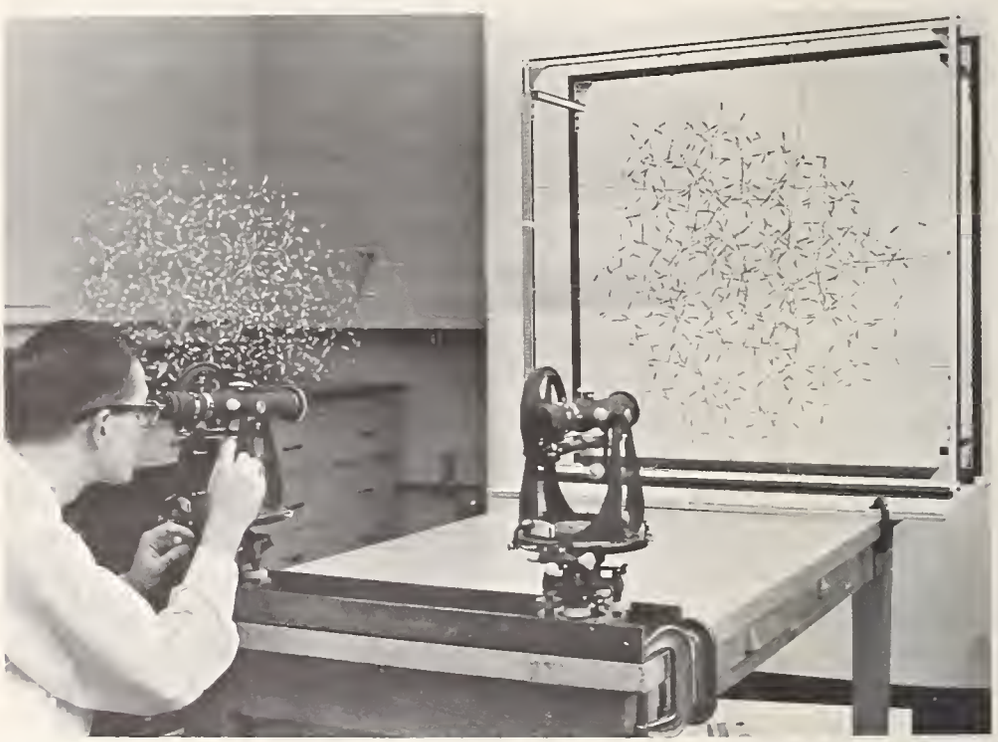
In this work, various forms of bismuth oxide and the effect of adding 33 selected oxides to these forms were studied by means of high-temperature X-ray and differential thermal analysis. The first part of the studies showed that bismuth oxide possesses two stable and two metastable forms; the con-

ditions for these formations were determined. In the oxide-addition portion of the study, phase diagrams showing the relationships between temperature, composition, and phascs present were constructed. The results clarified previously conflicting findings and provided a background of fundamental new data.

Random Network Models for Liquid and Glass Studies. Bureau scientists are studying the molecular arrangement of silica glass and liquid water by employing wire random network models of the type first made at the Bureau about 1957. The concept of a "random network theory" has been discussed qualitatively, but the only previous structural models receiving detailed quantitative consideration have been unrealistic complex arrangements of high symmetry.

In the present study, the models are synthesized according to a set of rules representing the conditions of a real condensation process. Normal condensation leads to the random network, but if a single six-membered ring of the crystalline structure is present as an initial nucleus, then the condensation process leads to the crystalline structure entirely.

For the quantitative study of the statistical topology and geometry of these new models, high-speed computer techniques are being used. At present the data are obtained by determining the coordinates of each unit in the actual physical model, but better statistical data may be obtained eventually from larger models whose synthesis is entirely mathematical.



Determining positions of structural units in a random tetrahedral network representing molecular arrangements in such important materials as silica glass and liquid water. Understanding the structure of such materials would shed much light on their properties. **(See p. 104.)**

Vapor-Pressure Studies. A program for defining the general problems involved in making precise vapor-pressure and heat-of-vaporization measurements, seeking solutions to these problems, and applying new techniques to vapor-pressure measurements of the platinum metals group is being conducted at the Bureau with the support of the National Aeronautics and Space Administration. A vacuum microbalance technique has been developed and applied to heat-of-vaporization and vapor-pressure measurements of platinum, iridium, rhodium, palladium, ruthenium, and osmium at temperatures near 2500 °K. Measurements of the latter two elements have been completed during the year.

Improved measurement techniques have successively increased the precision and accuracy of the data obtained in the studies. As a result, sources of measurement error originally masked by the scatter of the data and thought to be insignificant are now detectable.

Attempts to measure vapor pressures of the platinum metals in the range of 10^{-12} atmospheres (atm) resulted in an abnormally low vaporization rate, as the substance evaporated into a vacuum of about 10^{-9} atm. Impurities such as oxygen or carbon may form a stable layer on the surface of these substances, thus inhibiting the vaporization process, but a much more thorough investigation must be undertaken before definite conclusions can be drawn.

Crystal Structure Determinations. In studying the structure of matter by X-ray diffraction, several compounds have shown interesting and unusual characteristics. For example, the structural determinations of barium tetraborate (BaB_4O_7) revealed an unusual, previously unknown, boron-oxygen network consisting of well-known subunits of linked six-membered boron-oxygen rings. Half of the boron is tetrahedrally coordinated and half is triangularly coordinated. The barium-oxygen and barium-barium distances correlated very well with the cation distribution in glasses as determined by X-ray radial distribution studies.

The structures of sodium trimetaphosphate ($Na_3P_3O_9$) and sodium trimetaphosphate monohydrate ($Na_3P_3O_9 \cdot H_2O$) are unusual in that the hydrate has the same basic structure as the anhydrous salt, although the material is not zeolitic. Other structural investigations were recently completed on 1-ethyldecaborane, lithium dipotassium trimetaphosphate monohydrate ($LiK_2P_3O_9 \cdot H_2O$), and sodium tetrahydroxyborate dihydrate ($NaB(OH)_4 \cdot 2H_2O$), whose structure was determined by a direct method which tested new phase determination equations.

Phase Change Studies of Silica-Metal Oxide Systems. Phase changes in silica-metal oxide systems result in varying degrees of opalescence. Such changes, noted in immiscible liquid studies, may have application in improved turbidity standards.

In the immiscibility studies, lowering the temperature of a homogeneous mixture of liquids to a particular critical temperature caused a new liquid phase to appear as droplets at many points throughout the liquid. These droplets subsequently coalesced into larger droplets and finally formed a separate immiscible layer. If a homogeneous liquid mixture is cooled below

its particular critical temperature, the new liquid phase occurs spontaneously; yet the high viscosity of the homogeneous mixture at this temperature inhibits coalescence, allowing the early stages of phase separation to be observed.

Phase change studies at the Bureau, conducted in silica-metal oxide systems, show that, aside from droplet-shaped phases, a continuous fibrous network is formed. This fact suggests the presence of a nucleating polymer network in the homogenous melt before phase separation occurs. A study of these nucleating phenomena, and of the subsequent coalescence process, shows that glasses having a controllable degree of light scattering can be produced. Glasses of this type are being evaluated as turbidity standards to replace less durable plastic and liquid standards presently in use.

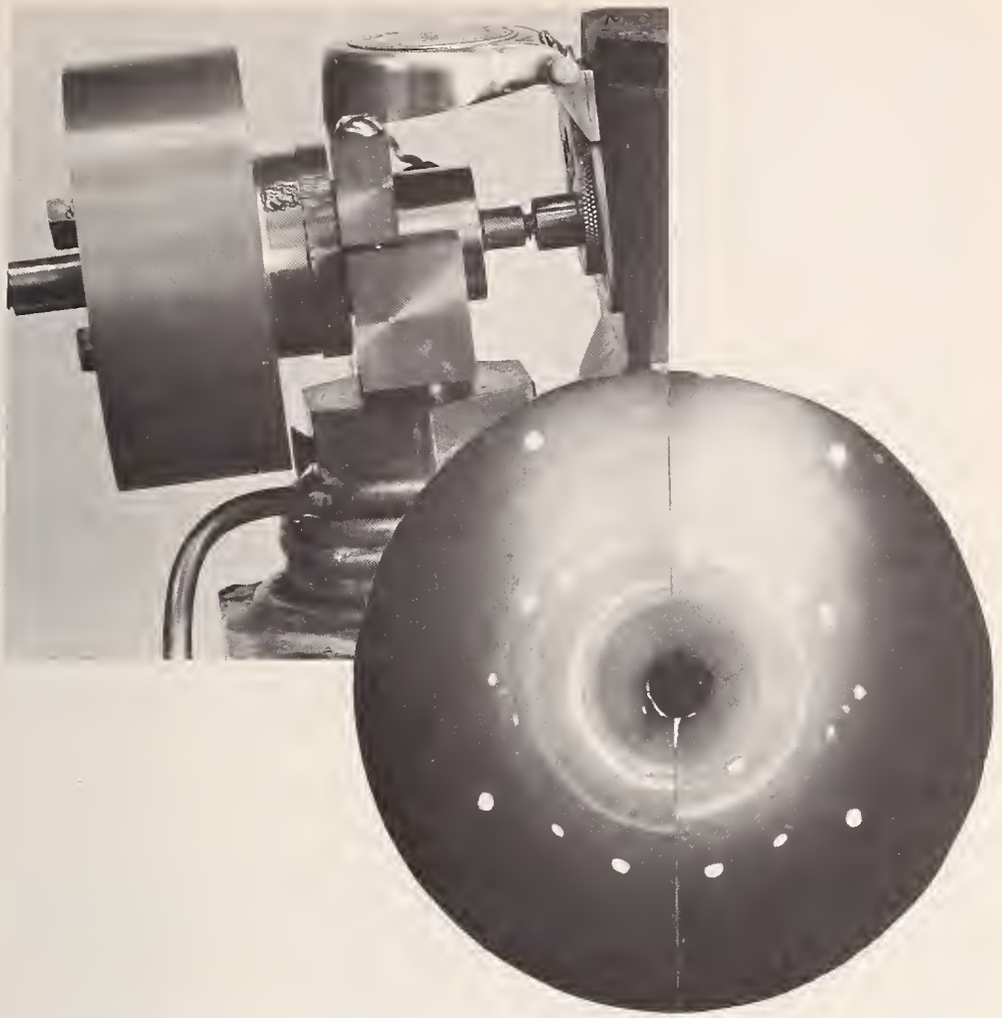
Standard Glasses for Viscosity Measurements. Standard glass No. 710 (soda-lime-silica) has been issued as a standard for calibrating commercial glass viscometers. Another glass No. 711 (lead-silica) is now being processed and will soon be ready for domestic and foreign distribution as a second viscosity standard. Laboratories carrying on extensive research programs, and laboratories committed to routine physical properties measurements, have created a strong demand for standard glasses of this type.

A second series of glasses, two- or three-component glasses of high purity, will be made for use in studies concerning the constitution of glasses. Through systematic studies on properties of simple glasses from a common source, information can be gathered and correlated to give positive results and interpretations concerning the structure of glass.

Elastic Constant Data. The Bureau conducts a program of refining and improving methods of determining elastic constants of various materials. In determining such values for rutile (TiO_2), three of a set of six values disagreed with values reported elsewhere. Subsequent checking showed that if the values used in the previous work were corrected for their crystallographic orientations, good agreement could be obtained. The values for rutile are now regarded as well established.

Velocity of sound measurements should be made along symmetry axes in cubic crystals because the resulting equations for computing elastic constants are then much simpler. The Bureau has put the equations into a form suitable for use along any axis. These equations have been tested by redetermining values of the elastic constant of strontium titanate, and good agreement was obtained with previous values. This method has been used to determine the elastic constants of uranium dioxide.

Structural Studies of Materials Under High Pressures. Many elements and compounds may be changed from one crystalline form to another by varying the temperature or pressure or both. This phenomenon, generally known as polymorphism, is more specifically known as allotropism for the elements. Phase transformations occur more often with pressure variation than with temperature variation. Until the crystal structure of these polymorphs is determined, data on the physical properties of the high-pressure phases are of limited value.



Left: **X-ray diffraction camera which incorporates an opposed diamond-anvil pressure cell.** ***Right:*** **Matched X-ray powder diffraction patterns of potassium iodide showing high- and low-pressure forms. Left half represents the normal face-centered cubic structure at 1 bar. Right half, at 20 kilobars, shows a simple cubic structure. The pattern of the salt is shown by the rings and arcs. The spots are due to diffraction from the diamonds.** **(See p. 106.)**

The Bureau has developed an X-ray powder diffraction camera for obtaining structural information on materials subjected to pressures as high as 70 kilobars. This technique is useful for showing that a real transformation exists, particularly in those cases where other techniques, such as electrical resistance and density measurements, either give ambiguous results or erroneously indicate the absence of real transitions.

In applying this high-pressure device to studies of the alkali halides, potassium and rubidium halides and also cesium fluoride, were all shown to have a sodium chloride-type structure at 1 atm and 25 °C, and convert to a cesium chloride-type structure at elevated pressures.

Other studies on some rare-earth metals have shown that allotropy exists in lanthanum, cerium, praseodymium, and neodymium at elevated pressures. The structure-types of these rare-earth allotropes are being determined.

Mechanical Properties of Ceramic Bodies. Many mechanical properties of brittle polycrystalline bodies are extremely structure-sensitive. Knowledge of this structure sensitivity is essential to intelligent measurement and control of the mechanical properties of such materials. To help meet this need, the Bureau, partially supported by the Atomic Energy Commission, conducts studies of the influence of microstructure on the strength and elasticity of brittle polycrystalline bodies—in particular, ceramic bodies.

The strength of such bodies strongly depends on their grain size and the minimal degree of continuity within them, the latter being thought of in terms of porosity. Only the very general trend of this dependence was previously known, namely that their strength decreases with an increase in either porosity or grain size.

In the present study, a more definitive approximation of this dependence was formulated. For example, the studies showed that the strength of porous brittle polycrystalline bodies decreases approximately logarithmically with both increasing porosity and a logarithmic increase in grain size. This approximation is applicable for ceramic bodies of alumina, beryllia, magnesia, thoria, urania, and chromium carbide. The approximation, expressed in equation form, is gaining some acceptance in the field of ceramics as a useful empicism.

Other efforts in the present study have been toward developing a micrographic measure of the minimal degree of continuity within ceramic bodies. Such a measure has been developed and is being utilized at present to derive a truer and less empirical representation of the structure sensitivity of the strength of brittle polycrystalline bodies.

2.2.4. METALLURGY

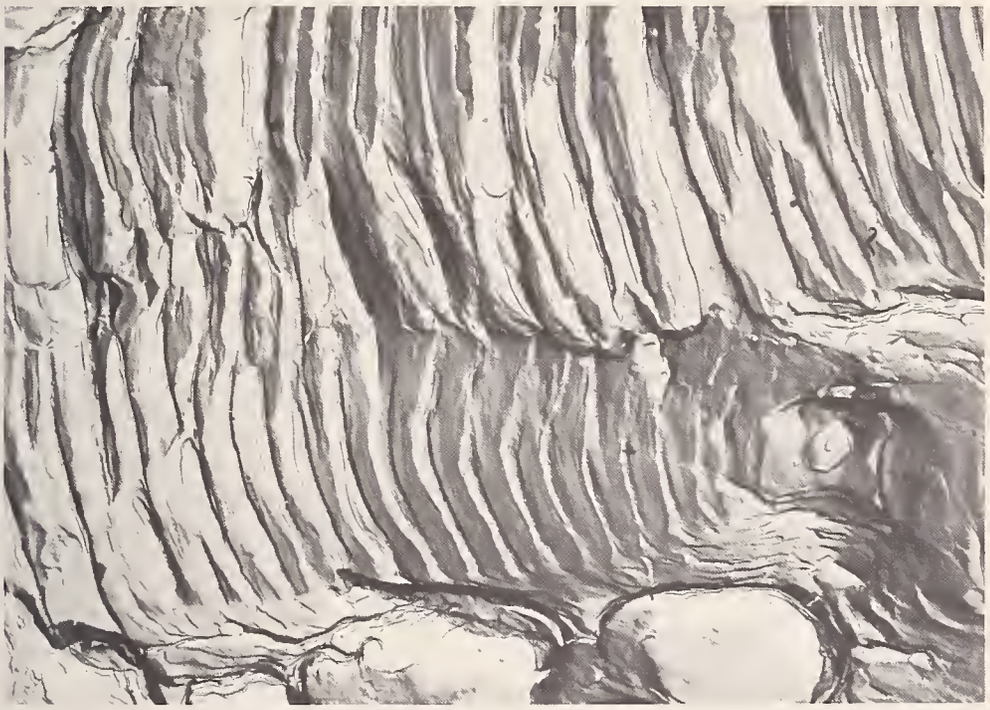
Metallurgical research is directed primarily toward increasing our understanding of the properties of metals in order to encourage the optimum use of existing metals and alloys and to stimulate the development of new ones having desirable properties. Broad programs of fundamental and applied research are conducted which attempt to relate the macroscopic properties of metals and alloys to their known structure. Crystal structure and the role of dislocations and point defects are of primary importance, although in some cases more gross structural features such as grain size, shape, and distribution are investigated. The electronic structure of metals and alloys is investigated to obtain basic knowledge on the cohesion of metals. Important phenomena in metallurgy such as diffusion, crystal growth, fatigue, plastic deformation, and corrosion are studied intensively, and explanations in terms of atomic mechanisms are developed.

The metallurgy laboratories also provide advisory services to other Government agencies, particularly in connection with the investigation of service failures of transportation equipment. Participation in the Bureau's standard samples program by the development of specific standards of gases in metals is another activity.

Metal Fatigue Investigated in Aluminum Alloys. In a recently completed investigation of the effect of environment on the fatigue strength of aluminum alloys, tests were conducted in which the humidity was changed during the test. Although a high-humidity atmosphere is detrimental to fatigue strength, the results of this investigation showed that the environment during the initial part of the test has no effect on the total number of cycles to fracture. As stressing is continued beyond this initial period, fatigue cracks develop rapidly if moisture is present and slowly if the atmosphere is dry.

Many of the fracture surfaces of the specimens tested in this investigation showed small areas of brilliant color. Optical and electron microscope examination disclosed that the colored areas had marked striations, due to the progress of the crack front with each cycle of loading. Where the striation spacing was about equal to the wavelength of visible light, the surface served as a diffraction grating to produce the observed colors.

Properties of Metals at Elevated Temperatures. Creep tests, made below 1200 °F on cold-drawn and aged specimens of a nickel-aluminum alloy, showed that the creep properties of the metal were improved by prior cold-drawing. Additional improvements were obtained by aging the specimens prior to testing in creep. Conformance to current theories of deformation was obtained only over limited ranges of temperatures and stresses,



Observing colored areas on a metal fatigue fracture surface, NBS scientists took electron micrographs to determine the microscopic structures responsible for the color effect. They found that striations are caused by the intermittent progress of the crack front with each cycle of load; where the spacing is sufficiently regular, the surface behaves like a diffraction grating to produce the color phenomena. (6,000×) **(See p.109.)**

due in part to microstructural changes and to precipitation occurring during the tests. Light and electron microscopy showed that the size of the slip bands, precipitates, and subgrains increased with increase in test temperature and with decrease in stress.

Some data were obtained in a study to determine the influence of elevated temperatures (up to 1200 °F) and stress systems on the tensile properties of a titanium—8 aluminum—1 molybdenum—1 vanadium alloy. Initial results indicate that the flow and fracture strengths increase with increase in notch depth and with decrease in notch angle or root radius. Additional research is being conducted to correlate the relations of atomistic structure of metals to engineering properties of these metals.

Gage Block Materials Demonstrate Desired Stability. Two types of gage blocks developed during the past few years indicated a dimensional stability of better than 0.1 microinch per inch per year. Seven additional types, all having a surface hardness of R_c 65 or greater, were produced which exhibit stability of betwen 0.1 and 0.2 microinch per inch per year. This degree of stability meets the target requirements of the project. Research is continuing to further improve other properties (thermal, corrosion, wear) and to establish performance characteristics over longer periods of time. Studies to determine the nature and kinetics of some of the less understood processes causing instability are being continued.

Deformation of Metals Studied at Low Temperatures. The effect of multiaxial stresses induced by notches on the tensile deformation and fracture characteristics of metals is being investigated at low temperatures. In current work, annealed specimens of type 310 austenitic stainless steel, a ductile metal of face-centered cubic structure, are being used. Tensile specimens are of circular cross section and have circumferential notches of selected geometries and depths.

Data obtained in tests at room temperature on deeply notched specimens showed that a crack initiated in the region at the root of the notch at a relatively low strain grows slowly with additional deformation of the specimen. For example, a visible crack was initiated in a specimen at a reduction in area value of approximately 20 percent at the notched section, even though the reduction in area at the maximum load condition was nearly 30 percent and the reduction of area at complete fracture was 55 percent.

Further studies are in progress to determine the specific effect of the geometry of the notch on the deformation and fracture characteristics of this steel.

Slack-Quenching Technique Developed. The best combination of high strength and ductility of structural steels is usually obtained by complete hardening and tempering. Although it is known that incomplete hardening (slack quenching) with or without tempering results in an inferior combination of strength and ductility, quantitative evaluations of its deleterious effect have not been possible because of lack of means for producing specimens with controlled amounts of slack-quenched structures.

Suitable techniques were developed during the past year, and the effect of slack quenching upon the tensile and fatigue properties of steels is being studied.

Stress Corrosion of Carbon Steels. In experiments with notched specimens of four different low-carbon steels, intercrystalline stress-corrosion cracks formed in pairs at the roots of notches in ammonium nitrate solutions, with no evidence of hydrogen evolution. On the other hand, single cracks formed in acetic acid-hydrogen sulfide solutions that were primarily transcrystalline and there was evolution of hydrogen. It is therefore not likely that hydrogen plays any part in the stress-corrosion cracking of low-carbon steels, and that hydrogen embrittlement is an entirely different type of phenomenon.

Effect of Applied Current on Aluminum Corrosion. Studies of the effect of current on the corrosion of aluminum showed that continuously applied cathodic currents provide cathodic protection of the metal in neutral and acid sodium chloride solutions, but that cathodic corrosion occurs in alkaline salt solutions.

Corrosion Reactions Studied at Metal Surfaces. Experiments on the initial stages of the oxidation of iron at room temperature indicated that the rate of oxidation depended on the pressure below about 10^{-4} torr, but that it was pressure independent above that pressure. The increase in thickness at the lower pressures varied linearly with time at the beginning of the process, as predicted by the Cabrera theory.

The nature of the films formed on anodically polarized iron surfaces was also investigated. It was found that the passive films formed in both acidic and slightly alkaline solutions were three-dimensional compound films rather than oxygen monolayers as stated in some theories.

Studies of the initiation of metal oxidation with the field emission microscope, partially supported by the Advanced Research Projects Agency, were continued during the year. At low oxygen pressures, the formation of nickel oxide showed a strong dependence upon the metal crystal face.

Pure Alloys Prepared. Some projects under way at the Bureau require special alloys of high purity or with other special properties. Since they are not available commercially, a laboratory was set up for the preparation of such materials. Typical examples of those prepared during the year were high-purity magnetic and nonmagnetic alloys less than 325-sieve size for nuclear magnetic resonance studies. Several series of high-purity alloys were made for corrosion studies and special ternary alloys of molybdenum, chromium, and nickel for other types of research.

Standard Samples. The gas-content analyses of samples of unalloyed titanium and of an 8 percent manganese-titanium alloy were received from cooperating laboratories and the analyses are being evaluated prior to the issuance of the materials as standard samples. The gas content of three other titanium alloys and of four steels is also being determined, so that they may be made available as standard samples.

Equilibrium Diagrams Developed. NBS metallurgists, in work for the Atomic Energy Commission, studied the metallic reactions between uranium and the individual elements of the platinum metals by measuring the properties of the respective alloys. The resultant data, presented in the form of equilibrium diagrams, show the compounds formed between two elements, the temperatures at which the metallic reactions occur, the mutual solid solubilities, and the transformation temperatures of uranium. The diagrams form the basis for further theoretical work on the interactions of the individual metallic elements.

Experimental Alloy Demonstrates Usefulness. The superiority of the 60 chromium–40 nickel binary alloy over conventional iron-base alloys, when subjected to corrosion-erosion attack in oil-fired naval boilers, was exhibited both in laboratory tests and in actual usage on naval vessels. Further tests showed that the resistance of the alloy can be improved by the addition of certain elements, and by preparation under vacuum conditions rather than by melting under an argon atmosphere. This work was supported by the Navy Bureau of Ships.

Steel Pilings Inspected. Under the sponsorship of the American Iron and Steel Institute, *driven* steel pilings which had been in service for from 7 to 40 years in a variety of soil conditions in the country were inspected during the year. No appreciable corrosion was found in "undisturbed" soils below the water table regardless of the type of soil into which the pilings were driven. Above the water table some, but not serious, corrosion was found. These results contradict those often obtained on pipes and other materials *buried* in "disturbed" soils, and the reason for these different findings is being sought.

Correlation Effects for Impurity Diffusion. Since an impurity atom in a metal can strongly affect the vacancy jump frequencies in its vicinity, correlations between the directions of successive atom jumps are especially important to studies of impurity diffusion. In recent research, detailed calculations were made to determine the effect that dissociation and re-association of vacancy-impurity complexes has on these correlations, and a nonzero lower limit was established. The resulting equations allow a more detailed description of vacancy jump frequencies near an impurity.

Electron Microanalysis Provides Basic Data. The Bureau's electron probe microanalyzer, which permits quantitative chemical analyses *in situ* to be made at a 1-micron level of spatial resolution, was used to investigate the uniformity of elements in low-alloy standard steels. An NBS steel, designated Standard Sample No. 461, was found to be uniform on a microscale in both iron and nickel. A decomposition mechanism for columnar grains formed by nitriding a titanium alloy was also deduced with the aid of the microanalyzer. Theoretical work was directed at the methods used for reducing directly obtained X-ray intensities to chemical compositions.

Quantitative Metallography Derived With Computer. A data-processing program for the automatic quantitative analysis on micrographs of an NBS electronic computer was completed and applied to a number of

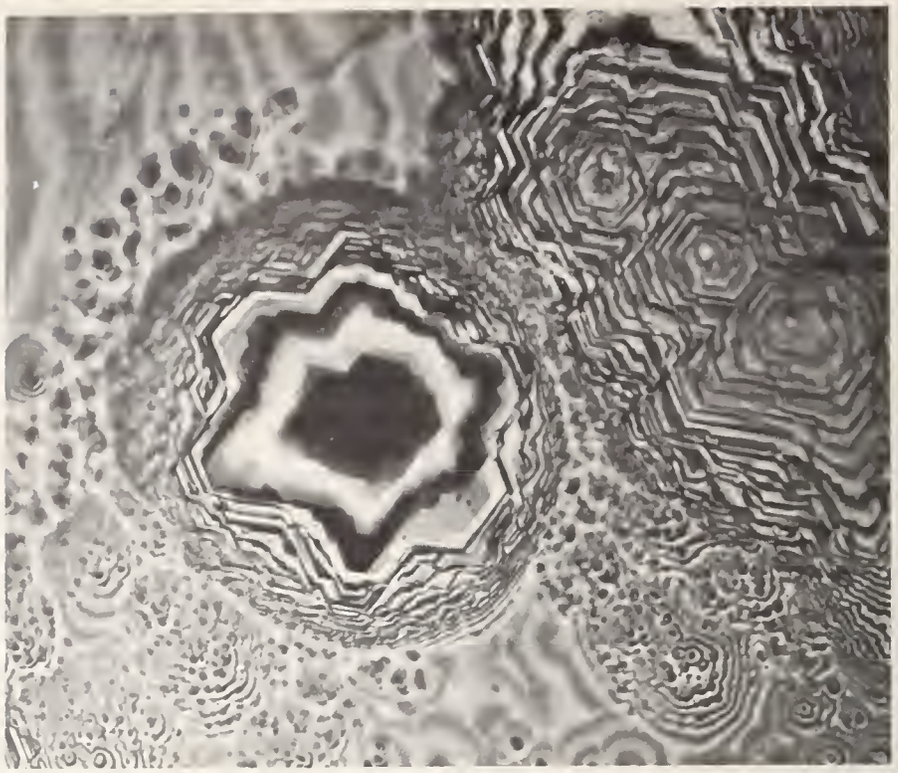
research problems. In this program, 28 picture control and analysis operations are achieved by simple orders in English format. During the year, analyses were completed on a series of color micrographs of niobium-tin superconductor wire and on the microstructure of a steel designated Standard Sample No. 461. Work was undertaken to develop a standard for graphite particle size in ferrous materials by means of the computer technique. Feasibility tests were conducted on micrographs of photographic emulsions and on biological micrographs in the fields of chromosome identification, cancer cells, and nerve cells. The program was found generally applicable to these types of micrographic problems as well as those in metallurgy. Programming is in progress for a more extensive and faster system on a new NBS computer.

Anisotropic Effects Studied in a Cubic Alloy. An investigation of the Pb^{207} nuclear magnetic resonance absorption linewidth in a series of lead-indium alloys as a function of applied magnetic field revealed a broadening mechanism heretofore unobserved in alloys. This source of line broadening arises because of the interaction between nuclear spins and unpaired electron spins outside the nucleus. It vanishes when the resonant nuclei have local cubic symmetry. The presence of this field-dependent "anisotropic Knight shift" broadening is possible in the face-centered cubic phase of the alloy because of the deviation from local cubic symmetry at the Pb^{207} sites produced by adding indium atoms, and the broadening indicates a large anisotropy in the electronic wave functions at the Fermi level in this alloy.

X-Ray Diffraction Employed for Crystal Structure Studies. This work is concerned with the analysis of lattice stresses as deduced from interatomic layer strains, measured from X-ray diffraction data. Some results concerning residual stresses in plastically deformed steels were published, and a study is now in progress on coarse-grained polycrystalline samples. Also under way is an investigation of crystal perfection by means of fine-focus divergent beam X-ray techniques.

Dislocations in Metals Investigated. The effects due to dislocations in metals are currently being examined from several points of view. Transmission electron microscope methods are being employed to examine stacking faults and twins in high-purity copper. Thermal evaporation from cleavage surfaces of zinc single crystals was found to occur preferentially at dislocations. The detailed shapes of the resulting evaporation pits were studied as a function of vapor undersaturation and surface impurities. Step configurations on the zinc surfaces were examined by electron microscope replica techniques. The vapor deposition of gold on these surfaces is also being employed to study the surface steps that are related to dislocations in the crystals.

Kinetics of Whisker Growth and Evaporation. In Bureau studies of the kinetics of metal whisker growth from the vapor phase, it is assumed that growth takes place by adsorbed atoms surface-diffusing to a sink (an emergent screw dislocation) at the whisker tip. But the problems of de-



Optical interference micrograph of a thermal evaporation pit on a zinc surface. These pits are being studied for information on the effect of dislocations on metal behavior. (460×) **(See p. 113.)**

scribing growth rate as a function of pressure, the evaporation time of adsorbed atoms, and the surface-diffusion coefficient are complicated by the occurrence of moving boundary conditions. Hence, an integral equation which incorporates these conditions was derived and programmed for the Bureau's electronic computer. The resulting numerical solutions should be useful in analyzing the experimental data thus far obtained on whisker growth.

In work partially sponsored by the Advanced Research Projects Agency, data on the growth and evaporation kinetics of crystal whiskers of potassium and of mercury were obtained from direct optical measurements in sealed-off vessels prepared by ultra-high-vacuum techniques. The data were compared with theoretical estimates obtained from solutions of the surface-diffusion equation. Over certain ranges of vapor undersaturation, crystal edges were not found in this work to act as evaporation step sources; the subsequent growth and evaporation of whiskers appeared to be quite symmetrical processes that could be well described by a single surface-diffusion equation.

Properties of Electrodeposited Copper. Electrodeposited copper is an important material for electroforming and for other engineering applications; however, to improve and expand its usefulness in these applications, additional information is needed on the relationships between its properties and conditions of deposition. To fill this need a new program,

supported jointly by the American Electroplaters' Society, the International Copper Research Association, and the Bureau was initiated.

The microstructure of the deposits and their mechanical, electrical, and thermal properties will be determined and related to the type of plating bath and operating conditions. A similar study of electrodeposited nickel completed sometime ago was found to be of considerable value to the electroplating industry.

Electrocrystallization Investigated. A program was initiated under the sponsorship of the Advanced Research Projects Agency and the Harry Diamond Laboratories to study the growth of metal crystals by electrodeposition. This method of growing crystals offers a distinct advantage over other methods in the apparent ease by which the rate of growth may be controlled.

Polycrystalline masses, dendritic growth, and single crystal growth can be achieved from aqueous solutions and from fused salts. This flexible technique of growing metal crystals promises to yield significant information of scientific interest. The initial phase demonstrated the prevalence of growth twins in electrodeposits, and these twins appear to be related to the growth mechanism of dendrites and of dense deposits.

Distributions of crystal orientation in polycrystal electrodeposits of copper were determined for the first time and change in distribution accompanying deposit growth was found. Growth of copper dendrites showed a fivefold symmetry about the axis of growth.

Calorimetry Used To Study Fused Salts. A calorimeter, operated at temperatures up to about 800 °C, was constructed for measuring the heat effects involved in the formation of complex ions in fused salts. The formula of a complex formed from two salts can be determined by measuring the heat effects attending the addition of small increments of one salt to mixtures of the salts covering the whole range of composition. The heat effect varies with the composition of the melt. In current work, sponsored by the Atomic Energy Commission, the complex ions formed in a mixture of molten potassium chloride and cadmium chloride are being studied.

Peltier Effect Measured at Liquid Junctions. The flow of current across the junction of two electrolytes—for example, 1.0 molal hydrochloric acid in contact with 3.0 molal potassium chloride—results in either a heating or cooling effect at the junction, depending on the direction of current flow. This phenomenom, which is called the Peltier effect, is considered due to the existence of a voltage at the junction, and it is measured with sensitive thermistors. The value of the Peltier voltage is obtained by dividing the heat effect in joules by the current in coulombs. In a recent study, sponsored by the Atomic Energy Commission, the Peltier voltage was found to be about 80 mv for the two solutions mentioned and to be independent of the current density, the diffuseness of the junction, or the length of time that current was passed across the junction.

Cooperative Services Provided. Among the more interesting cooperative services of the engineering metallurgy laboratory performed during the year were the examination of stainless steel reflecting disks and support

arms for the Post Office Department (these disks are designed for attachment to Post Office trucks so that drivers may view the area immediately below the bumpers and so avoid striking small children); the examination. for the Interstate Commerce Commission, of the welds from a mobile propane gas tank that exploded with considerable loss of life and property in Berlin, N.Y.; and the collaboration with Bureau staff in the Engineering Mechanics Laboratory on the selection of stainless steel for large dead-weight testing machines.

2.2.5. POLYMERS

The Bureau conducts research on natural and synthetic polymeric materials—rubber, textiles, paper, leather, and plastics—which are composed of long, chainlike molecules. Many of the useful properties of these materials depend upon molecular size, shape, distribution, and flexibility. To aid in the efficient utilization of polymeric materials, the Bureau investigates the mechanisms involved in forming polymers, their constitution and molecular structure, and methods for measuring their properties. The data obtained are of value not only in developing new materials having specific properties, but also in devising standard techniques for evaluating those already in use and in preparing engineering standards to promote the economic growth of polymer industries.

Methods were reported during the year for the analysis of ethylene-propylene rubber, determination of bitumen content of expansion-joint fillers, measurement of tensile properties of paper and tongue-tearing strength of woven fabrics, identification of antioxidants in synthetic rubber, and nondestructive examination of internal structure of composite products by point-projection X-ray microscopy. Work was undertaken on the macroporous structure of leather, phase transformations in polymers at high pressures, phase equilibria in polymer solutions, thermodynamic properties of polymers, effect of pressure on the crystallization of natural rubber, and failure behavior of fibers at high impact velocities. Chemical investigations were concerned with radiation-induced polymerization at high pressures, synthesis of fluoroaromatic monomers and polymers, effects of gamma-radiation on polymer scission and crosslinking, structure of metallo-organic coordination polymers, production of two stereoregular forms of polyacenaphthylene, and adsorption of polystyrene from solution onto a metal substrate. Two standard samples of polystyrene were issued for calibration of molecular weight measurements. In research conducted in cooperation with the American Dental Association and Federal dental services, significant contributions were made to knowledge of the structure and strength of teeth, the analysis of gold alloys, and the improvement of dental cementing compounds.

Ethylene-Propylene Copolymers Analyzed. Elastomers prepared by random copolymerization of ethylene and propylene with Ziegler-Natta type catalysts are commercially important because of the low cost of the raw materials and the wide range of physical properties obtainable. To achieve the elastic quality of rubber, the propylene content of the polymer

must be controlled within certain limits. An analytical method developed for quantitatively determining propylene in both raw and cured copolymers is applicable over the entire range of propylene concentrations. The method is based on the fact that pyrolysis of ethylene-propylene copolymers produces characteristic unsaturated carbon compounds which are identified by infrared absorption spectroscopy. It was found that the ratio of the absorption of the vinyl groups to that of the vinylidene groups in the pyrolyzate varies reproducibly with the mole fraction of propylene in ethylene-propylene copolymers.

Bitumen Content in Expansion Joint Fillers Readily Determined. A comparison of a Soxhlet extraction method for the determination of bitumen content in expansion-joint fillers (made of bitumen and cellulose fiber, cork, or glass wool) with the current centrifuge method recommended by the American Society for Testing and Materials, showed that the Soxhlet procedure required less operator time and smaller amounts of solvent than did the ASTM method. With the Soxhlet procedure it was also possible to analyze a large number of samples concurrently with a minimum amount of attention. A statistical analysis of the data showed that the results obtained by both methods were in good agreement.

Tensile Properties of Paper. Tensile properties have long been used as a measure of the quality of certain papers, but in recent years they have assumed added significance in the efforts of manufacturers to develop stronger papers for shipping sacks and similar products. An interlaboratory study of the precision of test methods for tensile strength, stretch, and tensile energy absorption was therefore undertaken at the request of the Technical Association of the Pulp and Paper Industry to improve the precision of the measurement system. Twenty laboratories participated in the testing of 22 materials.

The results showed that a standard reference material would be of little or no value for standardizing the tests for tensile breaking strength and tensile energy absorption, although it might improve the precision of the stretch method used. The 95 percent probability limits for the differences between the averages for two sets of 12 measurements by each method were found for tests of the same material by a single observer, for tests of different materials measured under the same conditions, and for results obtained by different observers or instruments.

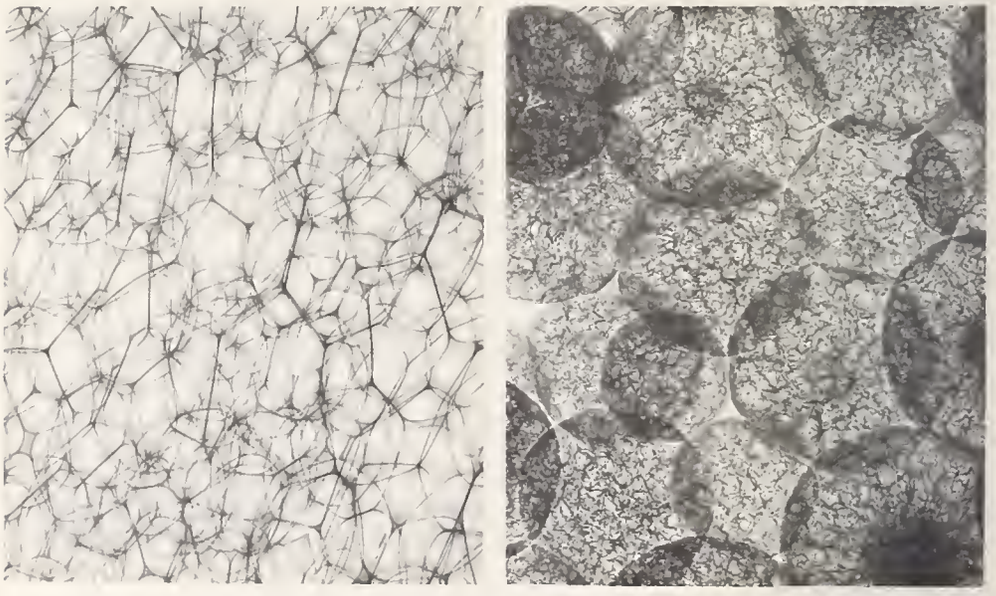
Tongue-Tear Methods for Woven Fabrics Evaluated. The tongue-tear (or "single-rip") method is widely used in measuring the strength of woven fabrics, but five different procedures have been standardized and published for this test. The Textiles Committee of the American Society for Testing and Materials therefore requested the Bureau to undertake a study of their relative precision. Thirty laboratories collaborated in the project, which was conducted by the Mandel-Lashof statistical plan with eight different materials.

The results showed that two of the procedures in which a constant-rate-of-elongation testing machine is used are better than the other three. In

one of the superior procedures, the result from an integrator average is computed and, in the other, an average of five peaks in the autographic record of the tearing load is used. The results also showed that five replicate determinations are needed for routine measurements and ten for interlaboratory measurements, and that a standard reference material would be of little value in improving the precision of measurement. Estimates were made of the precision of the five procedures for use in ASTM precision statements.

Color Tests Devised for Antioxidants in Synthetic Rubbers. A scheme of color tests was developed for identifying the five antioxidants commonly used in styrene-butadiene synthetic rubbers. These antioxidants include naphthylamine and diphenylamine compounds, styrenated phenols, and alkylated arylphosphites. By the use of specified successive tests involving two or more of a group of twelve reagents, the uncertainty of distinguishing between similar colors obtained with a single test is overcome. The procedure also permits the detection of small amounts of staining antioxidants, which might be present as contaminants.

Point-Projection X-Ray Microscopy Used To Study Polymers. Microradiography, a technique using soft X-rays generated by point-projection sources, is being applied to the examination of a wide range of polymeric materials. Because of its high resolution (greater than most light microscopes) and its ability to image opaque and thick specimens, this technique provides a powerful tool for polymer research. Studies were made on foams of polystyrene, polyurethane, vinyl, and other materials, to characterize cell structure and to correlate structural anisotropy with physical properties.



Point-projection microradiography is being applied to the study of polymers. This high-resolution technique can be used on opaque and thick specimens. *Left:* microradiograph of chemically modified polyurethane foam; *right:* fully expanded polystyrene beads. **(See p. 118.)**

In studies of paper formation, the method permitted detailed study of the size and location of fillers and additives. In addition, the condition and form of adhesives and reinforcing components in polymeric materials could be easily imaged by the method. The point-projection source also provides an efficient means of producing divergent-beam (Kossel) diffraction, which permits detailed analysis of the structure of crystalline monomers and of the changes occurring during solid-state polymerization.

Leather Macroporous Structure Investigated. The pore structures in leather and other natural collagenous materials, and in plastics and fritted glass disks were compared with a mercury porosimeter at absolute pressures ranging from 5 to 3000 psi. Pore radii corresponding to these pressures are in the macropore range from 50 to 0.04 microns (μ). The results demonstrated that many different pore sizes exist in the fibrous structure of leather, whereas the pores in manufactured materials are more uniform in size.

A differential analysis of integral volume-pressure curves derived for collagenous materials in the form of hides indicated that a large part of the pore volume occurs at radii of from 5 to 0.5 μ. In rattail tendons, a large fraction is in the 2.5- to 0.5-μ radius range. The volume from pores smaller than 0.25-μ radius is probably within the fibril region of the collagenous materials.

Structural Transformations Observed in Polymers at High Pressures. Physical changes under high pressure were observed in a variety of polymers compressed between diamond anvils at room temperature. The diamonds serve both as load-bearing surfaces for pressures up to 70 kilobars and as light transmitting media. The anvil device is placed on the stage of a polarizing microscope to increase resolution.

In the study, the optical appearance of some polymers (e.g., Teflon, Kel-F, and nylon 6) changed abruptly during compression. The original field, which showed little structure with shifting interference colors associated with increasing photoelastic strain, was changed to a reticulated structure with low birefringence. The transition point was usually marked by a snapping noise. Other polymers (natural rubber, polyisobutylene, and ethylene-propylene rubber) showed a more gradual transformation in which internal grooves developed and spread throughout the field with increased pressure until a reticulated structure resulted.

The transformations were irreversible, at least on a time scale of several months. X-ray diffraction patterns of compressed rubbers after removal from the anvil device showed crystalline rings which were not previously present. Polyethylene displayed a new spacing associated with a psuedo-triclinic unit cell. Polymers that transformed abruptly had a polymer glass transition temperature (T_g) above room temperature; those that transformed gradually had a T_g below room temperature.

Phase Equilibria in Polymer Solutions. Light-scattering studies of polystyrene-cyclohexane solutions near their maximum phase separation temperature showed differences in the distribution of molecular weights that

could not be easily determined by other physical chemical methods. The light scattered in the direction of the incoming beam was determined by measurement of the light scattered to the side and extrapolation to the forward direction. At a given temperature the scattering was measured as a function of concentration over a concentration range of from 1 to 10 percent. The temperatures varied from a few hundredths to a few tenths of a degree from the critical temperature.

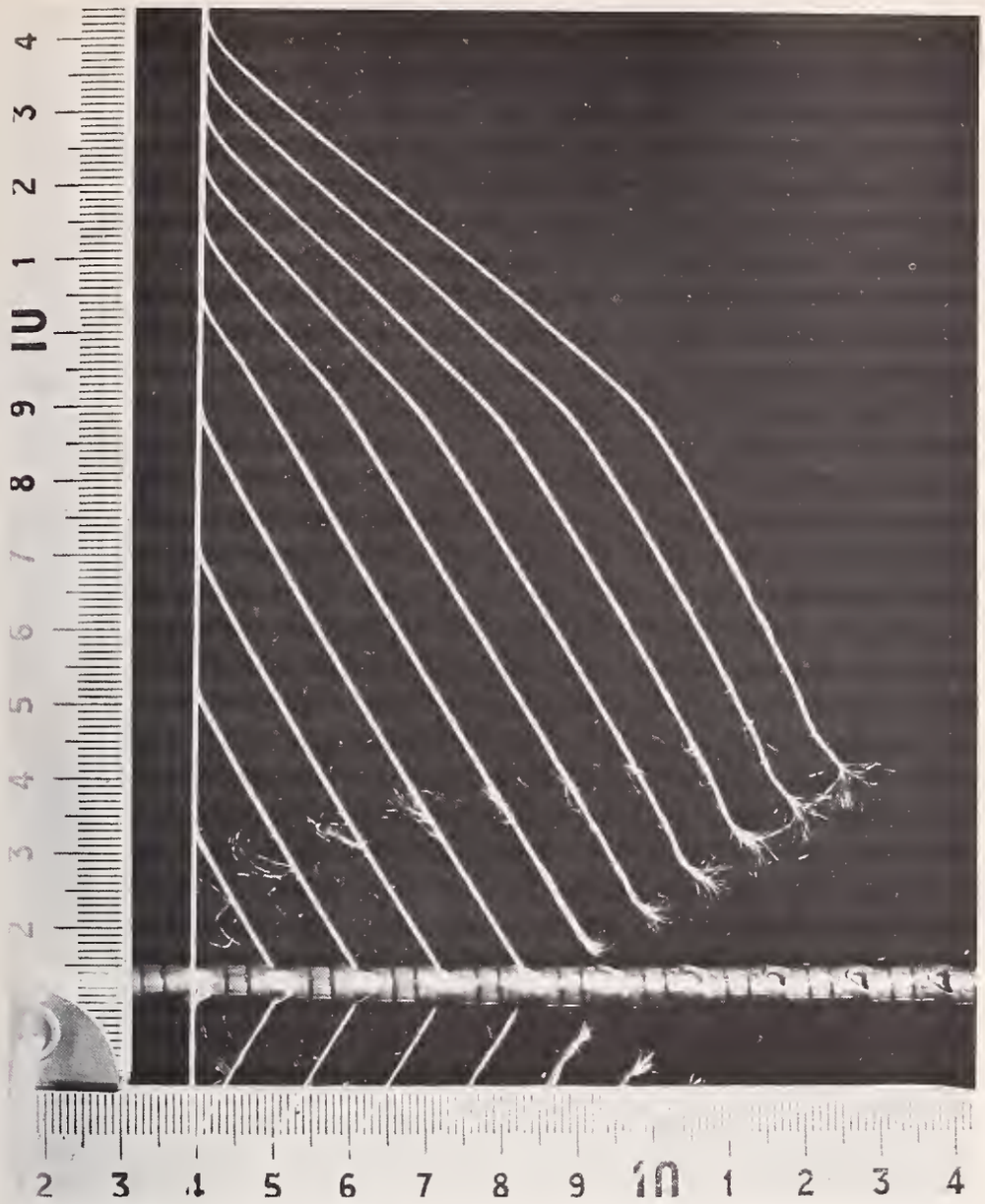
The shape of the resulting isotherms and the shift of the maximum indicated the polydispersity of the sample. The measurements obtained constitute a sensitive test for the existence of true monodispersity in a polymer. They also lead to a direct experimental determination of the thermodynamic properties of concentrated polymer solutions. The results show that current theory of phase equilibria in polymer systems does not satisfactorily fit experimental data, since it does not include concentration-dependent interaction terms in the critical region.

Statistical Calculations Made of Polymer Properties. Thermodynamic properties of polymer chains were calculated on a statistical basis in a recent Bureau study. Nonbonded nearest-neighbor, next-to-nearest-neighbor, and other interactions were counted, and, by introducing an appropriate potential energy of interaction between the neighbors, various thermodynamic properties could be derived. Attractive forces between neighbors led to very compact (supercoiled) conformations resembling tightly packed spheres. However, repulsive forces extending over a reasonably large range of intramolecular separations led to rodlike polymer conformations.

Computations were made of the free energy and of the entropy per link of polymer, with respect to a preselected reference state. This state corresponds to a conformationally unrestricted polymer coil. Variations in the thermodynamic properties of a polymer as it undergoes conformational changes could thus be derived. From such calculations it was concluded that the thermodynamic properties of polymers do not vary markedly with molecular dimensions. Even in a very good solvent, in which polymer-solvent contacts are favored over polymer-polymer contacts, polymer chains tend to remain in relatively coiled conformations.

Rubber Crystallization Investigated. The crystallization of purified natural rubber was investigated by observing the change in volume at temperatures from +10 to −30 °C under hydrostatic pressures up to 800 kg/cm^2. Superimposable Avrami type isotherms were found at all temperatures and pressures. A study was made of the effects of temperature and pressure on the critical free energy necessary to form a nucleus and on the activation free energy required for transport across a liquid-nucleus interface. It was found that the data could be quantitatively explained by means of a simple assumption that the activation free energy for transport was independent of the temperature.

Failure Phenomena of Fibers Studied at High Impact Velocities. When a filament is struck transversely, a V-shaped wave of transverse motion



Multiple microflash photograph of a textile yarn being broken by a rifle bullet. This method is used to study the behavior of textiles under high impact forces. **(See p. 120.)**

spreads outward at a velocity that depends upon the velocity of impact. Data on the wave velocities, corresponding to impact velocities between 10 and 700 meters per second (m/sec), can be analyzed to determine stress-strain behavior at straining rates of the order of 100,000 m/sec. In recent experiments, textile yarns were impacted with rifle bullets and a multiple exposure of the resulting configurations was obtained by means of microflash photography. The flash apparatus emitted a series of 15 flashes of 1-microsecond (μsec) duration separated by time intervals as short as 10 μsec.

It was found that the time required to break a yarn depended upon the impact velocity. For example, a high-tenacity polyethylene terephthalate yarn broke 10 μsec after impact at 620 m/sec, but required 100 μsec to break after an impact at a velocity of 420 m/sec. Similar relationships existed between impact velocity and the breaking tenacities and elongations of the specimens. Information of this type is sought since it gives a better understanding of the mechanical properties of polymers and their dependence upon molecular structure.

Radiation-Induced Polymerization Under High Pressure. To determine the influence of pressure on polymerization and to produce polymers of unusual or novel structure, studies are under way in which monomers that are nonpolymerizable under ordinary conditions are subjected to pressures near 20,000 atm and irradiated at 25 to 300 °C with gamma-rays.

Placing a monomer sample into a cobalt 60 radiation source 10 feet under water (*lower center*). Under the influence of the gamma radiation, high pressures, and high temperatures, several monomers which do not ordinarily form polymers have been polymerized. Polymers of unusual or novel structure with unique properties may be produced by such studies. **(See p. 122.)**

Monomers thus far polymerized in this investigation, sponsored by the U.S. Army Research Office, included perfluoroheptene, carbon disulfide, 4-chloroperfluoroheptadiene-1,6,perfluoropentadiene-1,4, and perfluorocyclobutene. The results showed that the rate of polymerization is usually proportional to the square root of the irradiation intensity. In several instances, polymers of promising physical properties and molecular weights were obtained. Equipment is being developed to conduct the polymerization at still greater pressures.

Fluoroaromatic Polymers Prepared. An intensive study of the chemical synthesis of new perfluoroaromatic monomers is being carried out under the sponsorship of the Bureau of Naval Weapons, with the objective of producing elastomers resistant to high temperatures. In this research, perfluorophenylene ethers were prepared from pentafluorophenol and its salts. The highest molecular weight polymer obtained exhibited interesting properties up to approximately 400 °C, the decomposition temperature of the material.

Perfluorovinylphenyl ether was also prepared and polymerized to low molecular weight polymers.

It is anticipated that perfluorophenylene methylene polymers would have outstanding thermal stability. As a precursor to the synthesis of this polymer, *p*-hydro-perfluorotoluene was prepared, and its ability to undergo anionic and cationic reactions was studied in a search for an efficient polymerization process.

High-Energy Radiation Effects on Polymers. A study of the changes induced in the physical properties of polymers by a high-energy radiation environment was undertaken for the National Aeronautics and Space Administration. Such information is needed to advance both space and nuclear technology. The results showed that the properties of an elastomer change drastically when it is irradiated. The radiation induces a series of complex chemical changes which lead to broken polymer chains and to crosslinking, with both processes usually occurring simultaneously.

In the investigation, stress relaxation resulting from the rupture of polymer chains was recorded for fluoroelastomers in a gamma-ray source. It was found that the dose required for 50 percent stress relaxation in a copolymer of vinylidene fluoride and hexafluoropropylene was 12 megarads (Mrad) in the absence of air and 6 Mrad in air, at a dose rate of 0.3 Mrad/hr. Similar findings were made on other fluoroelastomers. A rather large component of rupture was observed in the overall crosslinking of these polymers upon irradiation.

The rates of volatilization of polymers were recorded automatically while they were heated in a gamma-radiation field. A greatly enhanced rate of volatilization of polytetrafluoroethylene occurred at temperatures from 300 to 400 °C, far below the 500 °C temperature at which ordinary thermal decomposition becomes appreciable. Elucidation of the mechanism and thermodynamics of the radiation-induced degradation process is necessary before polymers suitable for use in radiation fields can be synthesized.

Thermal Stability of Coordination Polymers Investigated. In recent research, the thermal stability of coordination polymers of *bis*(8-hydroxy-quinoline) derivatives heated in vacuum was related to the metal atoms that linked the organic units (ligands) in the polymer chain. The decomposition temperatures of polymers containing either divalent manganese, cobalt, nickel, or copper decreased linearly from approximately 510 to 420 °C with increasing atomic number of the metal. A divalent zinc polymer, being more stable than the copper polymer, showed an interesting departure from this trend.

It was demonstrated that the mechanism of decomposition involved cleavage of the metal-ligand bonds at the coordination site and that the order of stability depended on such periodic properties of the metal as ionic potential and electronegativity. These findings may make it possible to predict the thermal stability of other coordinated systems and they may suggest structures for polymers of greater heat resistance.

Stereoregular Polyacenaphthylene Produced. A recent advance in polymer chemistry is the ability to synthesize stereoregular polymers by the use of special catalysts. Another approach to the preparation of these regular structures is through the use of monomers of high steric hindrance. The polymers formed from such monomers are expected to have stereoregularity due to crowding of the bulky side groups.

Since acenaphthylene has a very large group bridging the polymerizable vinyl group, the polymer formed from it should exhibit the extreme effects of steric hindrance, both in its polymerization kinetics and in its physical and chemical properties. The polymerization should occur in either a syndiotactic "rodlike" form or an isotactic, tightly coiled helix. Meticulous separation of the products of ionically initiated polymerization and characterization by infrared and nuclear magnetic resonance spectra show that both structures do in fact exist in polyacenaphthylene.

Polymer Adsorption. Polystyrene films adsorbed from cyclohexane on chrome surfaces were recently studied in work partly sponsored by the Bureau of Naval Weapons. Purpose of the study was to obtain a better understanding of the nature of the interface between glass fiber and polymer in reinforced plastics. In the study, ellipsometry was used to measure changes in the state of polarization of polarized light reflected from the film-covered surface. From these measurements, the thickness of the film was calculated to be about 200 Å. The film consisted of about 12g/100 ml of polymer and the amount adsorbed was determined to be approximately 2.25×10^{-4} mg/cm^2.

Molecular Weight Standards for Polystyrene. Research to improve precision and accuracy of measurements of polymer molecular weights, particularly by osmometry, light scattering, and ultracentrifugation, has culminated in the issuance of two standard samples of polystyrene for calibration purposes. These materials, the first molecular weight standards for polymers to be made available by the Bureau, will be of value to chemists in the characterization of industrial macromolecular products used in the

manufacture of plastics, rubbers, textiles, and paper. Molecular weight and intrinsic viscosity are given for each sample. Each sample is also characterized for ash content, volatile content, and refractive index increment and partial specific volume constants of the polystyrene-cyclohexane solutions used in light scattering and sedimentation molecular weight determinations.

Structure and Strength of Teeth. Electron microscope examination of developing enamel showed that mineralization begins by the formation of extremely thin ribbons of calcium phosphate which subsequently thicken to become fibrous crystals of hydroxyapatite, $Ca_5(PO_4)_3OH$. In cooperation with the National Institute of Dental Research, the crystallographic and chemical evidence concerning the nature of the ribbons was reexamined with the conclusion that octacalcium phosphate, $Ca_4H(PO_4)_3 \cdot 2.5H_2O$, is a better prototype for the ribbons than the presently accepted hydroxyapatite. These two salts differ greatly in their chemical properties, so that a distinction as to which salt comprises the ribbons is needed for an understanding, on the molecular level, of the calcification mechanism. For example, the presence of fluoride during the enamel formative state has pronounced influence on subsequent caries development. Fluoride is known to cause octacalcium phosphate to hydrolyze to the less soluble fluorapatite.

Dental calculus (tartar) consists of about 20 percent organic material in a matrix of calcium salts, mainly phosphates. Studies were undertaken to determine the composition of the organic portion for possible assistance in the search for agents that might reduce the formation of calculus. Organic layers at the junction of the calculus deposit and tooth tissue and throughout the deposit were demonstrated by their fluorescence. Chromatographic and electrophoretic analyses showed the presence of a mucoprotein (a carbohydrate-protein complex), indicating a possible role of salivary mucoid in the formation of dental calculus.

The small size of specimens that can be prepared from human teeth requires special techiques for measuring the tensile strength of enamel and dentin. Hence, a method was developed that employs a dumbbell type specimen of 0.0015-in.^{2} cross section, with notched ends embedded in resin. The resin ends fit into grips attached to the testing machine. The dentin specimens were long enough to permit attachment of ¼-in. strain gages for modulus determination. The tensile strengths of human enamel and dentin stressed at a head speed of 0.002 in./min were 1500 and 7500 psi, respectively. The modulus of elasticity of dentin was found to be 2.8×10^6 psi.

The studies in this program were sponsored by the American Dental Association and the Federal dental services.

X-Ray Spectrometer Used for Analysis of Dental Alloys. Standard reference samples were recently prepared for X-ray spectrometric analysis by melting the component elements—gold, platinum, palladium, silver, copper, and zinc—of a dental alloy in a high-frequency furnace and casting the alloy into disks. Compositions of the castings were subsequently checked by chemical methods. Optimum procedures for casting the sample and for X-ray analysis were established. Analytical curves were developed

relating concentrations to measured intensity of the X-ray lines Au L_β, Ag K_α, Cu K_α, Pt L_α, Pd K_α, and Zn K_α. The procedure is more rapid than wet chemical methods and the results appear to be sufficiently accurate for general purpose work. The American Dental Association and the Federal dental services sponsored this study.

Dental Cements. In other work for the same sponsors, it was found that partial substitution of *o*-ethoxybenzoic acid (EBA) for eugenol as a chelating agent results in the formation of improved dental cements. A typical cement is obtained by mixing powder containing zinc oxide, heat-treated fused quartz, and hydrogenated rosin with EBA-eugenol liquid. The resulting product has compressive, tensile, and shear strengths that are about three times those of presently available zinc oxide-eugenol cements. Solubility and disintegration as measured by various laboratory tests are equal to or better than those of zinc oxide-eugenol cements. The cement also shows reduced setting contraction and water sorption.

2.3. SPECIAL TECHNICAL SERVICE PROGRAMS

2.3.1. APPLIED MATHEMATICS

The Bureau's applied mathematics facility performs basic and applied research and provides advisory services on the application of mathematical and statistical techniques. Its services are available to other Government agencies as well as to the Bureau's staff. The facility uses modern computing equipment in support of its program.

During the past year the Bureau continued research in statistical and numerical analysis, mathematical physics, and operations research, all of which are fundamental to its mission. Extensive assistance was rendered in these areas and in digital computation. In the latter field, emphasis was placed on problem formulation and analysis in order to select and develop appropriate numerical methods. Automatic high-speed computing machines were utilized when appropriate. The mathematical program was devoted both to problems in engineering and the physical sciences and to government problems of business management and operation, sometimes called data processing problems. Progress was continued in exploration of the use of modern digital computers in the mechanical translation of scientific publications, for which the need is urgent.

The Bureau's applied mathematics program was strengthened by the active interest and support of other Government agencies. The Office of Naval Research and the National Aeronautics and Space Administration supported basic and applied research in numerical analysis and mathematical physics. The study of mechanical translation of scientific publications was jointly supported by the U.S. Army Signal Corps and the U.S. Army Research Office.

Numerical Analysis. Research in numerical analysis is of vital importance in contributing to the effective use of electronic digital computing

equipment, both in applying such equipment to scientific and engineering problems and in utilizing it as an aid to decision making by management.

If an asymptotic series is truncated at (or near) its smallest term, the resulting partial sum is often a good approximation to the wanted function $f(x)$, particularly for large values of x. Because of this property, these series are frequently used in computations, even though they are really divergent. Only a few scattered special results are known concerning the precise magnitude of the error committed by approximating a given function by a partial sum of its asymptotic series.

Current research is directed toward filling this gap. Considerable success has already been achieved with certain types of asymptotic series originating from second-order ordinary differential equations; some general theorems have been established giving precise, and realistic, error bounds which are easily evaluated. The theorems also show, for example, why these series provide inaccurate results near the boundaries of their regions of validity in the complex x-plane.

Asymptotic Expansions. Work continued on the determination of error bounds for the asymptotic solution in terms of Airy functions of second-order ordinary linear differential equations in regions containing a turning point, and on the determination of complete asymptotic expansions of such solutions.

Quadrature and Interpolation. The question of the existence and uniqueness of functions satisfying a given set of conditions was investigated. The use of equidistributed sequences in Monte Carlo quadrature was investigated, both theoretically and experimentally.

Numerical experiments were conducted on the computation of highly multiple integrals—more specifically, on the calculation of the fourth and fifth virial coefficients of an imperfect gas—utilizing a fairly arbitrary interaction potential. Despite much activity on this problem over the past five years, treatment of its numerical aspects remains unsatisfactory.

Linear Algebra and Matrix Theory. Bounds for the arithmetic minima of quadratic forms were determined and the structure of classes of copositive and positive quadratic forms was investigated. Theorems were given relative to the iterative solution of eigenvalue problems and to the iterative inversion of a matrix. Such problems are of central importance in a wide range of investigations extending from flutter of airplane wings and critical speeds to nuclear theory.

Machine Translation. The morphological phase of the problem of mechanical translation of Russian into English has been entirely completed. Theoretically, the syntactic integration phase can never be completed; but enough progress has been made to indicate the soundness of the "predictive analysis" scheme initiated at the Bureau. Coding for the section dealing with the mechanical determination of the clause and phrase boundaries within a sentence is progressing. As soon as it is completed, an open test of the method will be made on Russian sentences composed of words formed from the limited number of stems presently stored in the machine's glossary.

Mathematical Tables. In response to demand, Applied Mathematics Series 27, *Tables of* 10^r, and AMS 36, *Tables of Circular and Hyperbolic Sines and Cosines for Radian Arguments*, were reissued. Underway is a critical survey of all the Bureau tables series in view of the approaching completion of the *Handbook of Mathematical Functions*.

Digital Computations. The Bureau improved its computational facilities by replacing the IBM 1401 with an IBM 1410 computer. The 1410 computer is actually rented by the Harry Diamond Laboratories, U.S. Army, but is operated by the Bureau. In addition, the Bureau continues to operate an IBM 7090 and plans shortly to replace this with an IBM 7094. Both scientific and data processing problems continue to require extensive use of these computational facilities. In addition to performing computations on its own equipment, the Bureau assists other Government agencies in setting up problems for other computing machines. The experience gained in the performance of this service stimulated research in programming and computational methods.

About one-third of the computing services tasks performed during the year originated within the Bureau. The remainder were performed in assistance to such agencies as the Harry Diamond Laboratories, National Aeronautics and Space Administration, Bureau of Public Roads, Secret Service, Treasury Department, Veterans Administration, Peace Corps, U.S. Military Academy, and the Office of Civil Defense. Important computations were performed on problems in the thermal dissociation of diatomic molecules, diffusion and reactions in gases, polymers, multilayer adsorption studies, neutron cross sections, equations of state, and interaction radiation.

Among the many problems in the area of data processing where the economic desirability of supporting the development of Mach 2 to 3 supersonic aircraft, the comparison of different tax proposals, the analysis of check forgeries, the evaluation of applicants for the Peace Corps, the analysis of highway and traffic problems, and a comparison of securities marketing procedures.

Extensive research continued in the field of automatic programming and artificial programmer-oriented computer languages. A monitoring system which previously utilized the 1401 computer as a secretary for the 7090 computer was adopted and enlarged for the 1410 computer.

Statistical Engineering. The principal function of the Bureau's statistical engineering program is to advise the Bureau's scientific and technical personnel on the application of modern probability and statistical methods to physical science and engineering experimentation. The aim of the program is to help the Bureau's scientists and technicians conduct their research, development, and testing programs so as to reach conclusions of desired scope and reliability at the lowest possible cost under existing limitations of funds, equipment, materials, and personnel. Extensive services were rendered, ranging from short informal conferences to active collaboration with project leaders for periods of several months.

Research and Development. Two Bureau publications completed during the past year make available to the technical public many important results of the Bureau's research and experience in the adaptation and development of statistical methodology for application to calibration and experimental programs in the physical sciences and engineering. The first of these, "Realistic Evaluation of the Precision and Accuracy of Instrument Calibration Systems," J. Res. NBS **67C**, No. 2, 161–187 (Apr.–June 1963) is a very thorough treatment of the principles of probability and statistics that are fundamental to the description and evaluation of the sources of errors in a measurement process. The paper derives from these principles the appropriate techniques for assigning numerical bounds to the uncertainties of measurement results.

The second publication completed last year, *Experimental Statistics* (to be issued as NBS Handbook 91), was prepared under a contract with the former Office of Ordnance Research (now Army Research Office—Durham). Although originally developed with the needs of the Army in mind, it should be equally useful to other groups concerned with research and development, both within and outside the Government. The Handbook is intended chiefly for use by persons with an engineering background as a guide and ready reference on the planning and interpretation of experiments and tests relating to engineering design and development programs. Model work sheets and examples corresponding to the more common applications of statistics are provided.

The Bureau conducts a continuing program of basic research in probability and mathematical statistics to maintain and increase the effectiveness of statistical services. During the past year, a study of a new rank sum test for outliers was completed, and an algorithm was developed for obtaining an orthogonal set of individual degrees of freedom for error.

Research was continued on applications of probability theory to problems of the reliability of complex systems. A mathematical study was made of the reliability of a system with spare parts, where the spare parts can fail in storage as well as in use. An investigation was initiated of mathematical models for the description of changes through time in the probability distributions of characteristics of electronic devices. The dependence of these distributions on age and stress level was considered.

Experiment Design and Consultation. Major cooperative activities were in connection with the Bureau's calibration programs. Methods for representing the precision and accuracy of measurement processess and statistical designs for eliminating the effect of environmental factors are the subject of most of the consulting activities.

A good example of this collaborative activity has been the work for the Mass and Volume Section. In the calibration of a set of weights, different combinations of the weights are compared in such a way that a value for all the unknown weights is obtained. Such a schedule of weighing, called a weighing design, has redundancy in the sense that more observations are made than there are unknowns in order that there be a check on the precision of the measurements. New weighing designs have been created which incor-

porate a standard weight as an unknown as a check on accuracy. A program was provided for electronic computation of the results; this method greatly simplifies the maintenance of records on the accuracy and precision of the measurement process.

Mathematical Physics. Research in this area continued to be directed toward the application of mathematical techniques to the solution of problems in mathematical physics and the engineering sciences. Investigations included a combined theoretical and experimental study of the laws governing the nonlinear deformation of viscoelastic materials; the application of the "stroboscopic" method to the study of nonlinear ordinary differential equations arising from vibration, acoustical, and electrical circuit problems; the determination of bounds on solutions of problems involving elliptic operators, especially those of elasticity; research on the kinetic equations governing various plasma flows; and a study of the feasibility of measuring the atmospheric drag on a manned satellite by means of controls to be operated by the astronaut.

Plasma Research. Research was performed on basic problems in the physics of ionized gases, particularly on the dynamics of motion in the presence of magnetic and electric fields. This work is essential in supporting the basic research of the Bureau and is also important to the National Aeronautics and Space Administration. Emphasized were investigations of the interaction of solar corpuscular radiation and the magnetic field of the earth and of dynamic phenomena, which may affect the operation of plasma propulsion devices. In particular, the kinetic equation was subjected to detailed study, as was the structure of the correlation function and its application to plasma oscillations.

Theory of Satellite Orbits. Analysis of the drag-free motion of an artificial satellite on the basis of a theory developed at the Bureau was continued. Through the use of oblate spheroidal coordinates, it is possible to give an analytical representation of the gravitational field of an oblate planet, such as the earth, which is nearer the empirically accepted representation than any given previously. This permits a discussion of the motion of a satellite in terms somewhat different from those hitherto used. A so-called reference orbit was first established, and current work is concerned with the study of perturbations of this orbit produced by deviations from true oblateness, such as equatorial asymmetry and oblateness of the earth.

Operations Research. General areas of investigation during the past year included game theory, graph theory, weapon system simulation, Boolean functions, and mathematical models of distribution networks.

Significant progress continued on studying methods for finding maximum matchings (isolated sets of edges) in linear graphs and on extending the results to maximum degree-constrained subgraphs. The difficulty of the algorithms increased only algebraically (rather than exponentially) with the size of the graph. The convex hull of the incidence vectors describing the matchings of a graph was determined. This result is unusual in that it is not the one suggested directly by the combinatorial problem.

Work continued on surface imbedding of graphs, leading to an abstract characterization of surface duality, and a classification of planar imbeddings.

A long-range study of mathematical models of distribution networks continued, with a view to optimizing the locations of sorting centers and the degree of system centralization. A number of mathematical topics relating to the "warehouse problem" (optimal location of a single processing facility) were identified and explored. Investigations dealing with the (sometimes surprising) effects of buffer capacities in simple flow networks were initiated. Simulation studies of two distribution subsystems were carried out.

Other major activities included continuation of the analysis and simplification of Boolean functions (important in network circuit theory) and the analysis and simulation of missile system operation. In addition, demand for consulting and advisory services in operations research continued to increase.

New Computer Facilities at Boulder Laboratories. The mathematics group at the Boulder Laboratories took a significant step with the installation of a new 7090–1400 computer system. Even with the increased capacity of the larger and more efficient system, however, the workload has grown beyond the capability of single-shift operation. This was due in part to the greater use being made of automatic data processing by the Bureau's scientific and administrative staffs, and also to the extensive use of the Bureau's computation facility by other Government agencies. These include the Bureau of Reclamation, the Geological Survey (both of the Department of the Interior), and the Department of Agriculture.

Mathematics Group at Boulder Laboratories. The increased computational capability obtained with the new computer system made possible many studies by the Consultant in Mathematical Physics. These include such studies as those of two-phase liquid flow in a pipe, Fourier coefficients relative to attenuation measurements, and complex argument error function for computation to high precisions.

Computational analysis programs included development of a scientist-oriented computer-programming method called BOUMAC, which is intended to minimize programming required for certain computations. Other projects are typified by programming computation of inverse thermodynamic functions, computing constants for measuring network voltage insertion ratios, and an information-retrieval project conducted for the Cryogenics Data Center at the Boulder Laboratories.

Statistical Studies at Boulder Laboratories. Work in the field of statistics advanced programs dealing with optimum estimation of parameters of negative exponential distribution, the distribution of a Student's t statistic, estimating means and mediums, approximating distribution functions, and estimating parameters restricted to an interval. Applications of probability theory were made in deriving families of power distributions of received radio signals, analyzing variance in estimating precision of frequency standards, modeling personnel promotions stochastically, and estimating parameters of Poisson distributions.

2.3.2. DATA-PROCESSING SYSTEMS

The Data Processing Systems Division assists other Government agencies to use their data-processing facilities most effectively by serving as a central research activity for data processing within the Government. It works as a technical consultant to, and collaborator with, other agencies in planning and implementing improvements in automated handling of both numerical and nonnumerical information. To maintain its consultative facility, paralleling the growing use in Government of data-processing equipment, the Division must increase the competence of its staff and the versatility of its research facilities.

In providing interagency assistance, the Data Processing Systems Division engages in research and development involving the techniques of several scientific disciplines. Present activities include exploration of new components to determine their suitability for computer circuitry; studies of the properties of materials; development of techniques for extending automatic data processing in such areas as the processing of scientific information; investigation of design procedures for assembling components into prototype equipments and systems; exploration of the application of communication science to data processing and control systems; automatic acquisition and processing of data for the physical and behavioral sciences by integrating the characteristics of the human operator with those of the equipment; application of automatic data-processing techniques to decision-making functions and technical supporting services in the Government; and the operation of a center providing information on research and development in the fields of storage and retrieval of scientific information.

More effective utilization of the many types of ADP (automatic data processing) systems now in use or expected to be used by the Government depends on establishment of appropriate standards, especially of input to and output from systems. Considerable planning and effort were devoted to such standardization through both intragovernment and Government-industry cooperation. The Data Processing Systems Division participated in the standardization panel of the Bureau of the Budget's ADP Advisory Council and maintains an active staff member on the American Standards Association's Sectional Committee X3—Computers and Information Processing and its many subcommittees and task groups. The establishment of the American Code for Information Interchange (a 7-bit code) encouraged the Bureau to investigate means for converting data produced in different formats into the standard format.

Research Information Center. The Research Information Center and Advisory Service on Information Processing, sponsored jointly by the Bureau and the National Science Foundation, continued to collect and organize literature and bibliographic references covering a wide range of interests in information storage, selection, and retrieval. The collection of references to the available literature now numbers over 12,500 items. Collecting information on current and proposed research projects and identifying the

research workers in the field have been continued in order to provide such information when requested by personnel in Government and industry.

Preliminary indexing vocabularies have been set up for selected subsets of documents and the work of abstracting, indexing, and establishing subject control of the pertinent literature has continued. The first 35 items of the pattern recognition subset have been microfilmed and are now ready for experimental subject searches on the rapid selector. Descriptive cataloging rules and coding requirements for all items in the collection have been formalized for full compatibility with multipurpose machine processing.

The Research Information Center issued a state-of-the-art report composed of a bibliography of foreign developments in machine translation and information processing. Two preliminary manuscripts on automated computing techniques for literature announcement media and on paper-scanning and paper-handling techniques for use with film optical sensing devices are being edited.

A continuing literature search and survey of existing equipment and developments for printed character recognition, speech recognition, and code recognition is being conducted under the sponsorship of the Army Signal Supply Agency. An ancillary study deals with the special problems associated with recognition of Chinese characters; a possible approach is by arranging each character in certain topological relationships. The center is continuing to provide bibliographic and other services to cooperating workers in the field, to Government agencies, and to interested correspondents.

Components and Techniques. The study of new and existing components continued as basic to developing economical, higher speed, more reliable, efficient digital data-processing devices having lower power requirements. The importance in a system of the capability of producing fast rises and of measuring and resolving extremely short durations (e.g., one nanosecond) led to the study of ultrathin ferromagnetic films as potential high-speed random access memory elements. This in turn involved studies of a strip transmission line for producing drive fields and a sampling oscilloscope for measuring switching signals.

The technique of quantitative analysis of thin films by X-ray fluorescence also was studied. A new hysteresis loop tracer was designed and constructed for measuring the dispersion of the anisotropy axis in films. In this connection a study was made of the electronic integration methods used in making these measurements. Preliminary results indicate that the fidelity of the hysteresis loop presentation is significantly improved by a phase-compensation circuit in the integrator.

The characteristics of semiconductor devices, such as tunnel diodes and mesa, microalloy diffused, and epitaxial transistors, were studied by use of simulation techniques. A charge control model of a junction transistor was simulated on an analog computer to determine the best way of driving a switching transistor. The use of tunnel diodes and transistors was surveyed for very fast logic circuits. A counter circuit capable of counting up to 80 megapulses was developed, based on an 80-Mc/s triggerable flip-flop multivibrator incorporating tunnel diode–transistor circuitry.

In studying semiconductors and storage devices for memory and logical functions in computers and control circuits, the binary computer net was reappraised and the general computer requirements described mathematically in terms of digital repeater transfer functions. The description, considerably extended and refined, does not specify physical form or logical organization; this offers the prospect of comparing and evaluating, in common terms, computer nets differing widely in physical and logical aspects.

Scientific Information Processing. The development of a programming system for processing information-retrieval prescriptions, directed at information sources consisting of interrelated pictures and text, was continued under the sponsorship of the Patent Office and the National Science Foundation. A prototype system accepting English sentences which describe pictures of simple geometrical shapes was developed; it directed manipulation of the sentences and pictures to determine which sentences were correct descriptions of which pictures. This program used a general-purpose syntactical analyzer for phrase structure grammars, written for the 7090 computer. A machine grammar written for the relevant fragment of English was used as the basis for others, including larger fragments of English. A set of programs for anlysis of simple pictures was constructed in STRIP (a machine language developed for the SEAC). Finally, an algorithm was written for translation of analyzed sentences into a logical calculus.

Logical and mathematical investigations were conducted, also under the sponsorship of the Patent Office, on some aspects of the organization of scientific and technical information that relate to methods of classification, storage, search, and retrieval, for automatic information systems. Additional studies required for the picture-description matching program concerned flow problems, the structure of generalized matching of graphs, Boolean matrices, binary relations, and the formal aspects of disaggregation as related to forming interest classifications in models of information systems.

The project of mechanizing Patent Office searches for chemical compounds has reached the point of a completed experimental file of chemical structures containing 2400 entries. The encoded data cover more than 160,000 organic compounds. The HAYSTAQ search routine was operated on this file to test the search logic and determine areas of possible improvement, using about 385 different questions. Studies of the most frequent errors and variation in error sources were based on analysis of key-punching output and computer-based error checking. Research on file organization continued with the development of screening methods permitting increased search efficiency.

Ciphering rules originally developed at the Patent Office for representing chemical structures simply and uniquely were revised and expanded jointly by the Bureau and the Patent Office. Use of the rules was simplified and they were made more widely applicable, now covering, for example, optical isomerism and isotopic labeling. The rules are being expanded to include inorganic structures, further types of polymers, Markush (variable) struc-

tures, and partially indeterminate structures. An experiment is under way to test the adequacy of ciphers for data input and as the basis of screening and searching. The logic was worked out for a number of the manipulations necessary on the ciphers, and some preliminary computer runs were made.

An overall systems design was prepared for the Office of Technical Services (Department of Commerce) to aid it in managing the information associated with acquiring, advertising, and disseminating the report literature stemming from Government-sponsored research and development. The plan includes progressive mechanization of index preparation, announcement composition, processing requests for documents, inventory control, and processing documents into the OTS collection.

An experimental computer program for producing a permuted title index of technical reports is now completed. Another program operating on the same input was written to produce indexes by subject, corporate source, series number, contract number, and author.

Sales statistics were gathered, and orders and incoming correspondence were sampled to evaluate demand as a factor in determining prestocking and reprinting requirements. Information to give indications of user preference, ordering habits, and responsiveness to prices was also developed and evaluated. Based on this information, work was continued on the design of the mechanized order-processing system to incorporate inventory maintenance and control and the ability to produce operational statistics.

The design of a central machine file to simulate the functions of a massive card catalog was begun. The data-preparation scheme, the file-building programs, and the file-maintenance programs are sufficiently advanced for use in the various index programs and parts of the analyses of sales, users, and inventory.

Technical Assistance for Data Processing. Expanded assistance to laboratories at the Bureau identified potential areas for automatic data recording and processing, many of which had special data-logging and preprocessing problems. Technical assistance was provided following analysis to determine whether analog or digital techniques were applicable, after which the feasibility of the selected applications was demonstrated. Examples are the modular data-logging systems designed for use in experiments concerning the radial properties of magnetically contained plasma arcs formed at low and near-atmospheric pressures.

The program of developing modular units of data-logging equipment for use by other laboratories included the design, construction, and evaluation of the following modules: a digital multiplexer functioning as a 64-pole, three-position switch when used in conjunction with the shift register; a block reader reading punched paper tape in 12-character blocks; a relay register storing 16 four-bit characters in terms of relay contact positions; a ripple register storing up to 10 characters in a way permitting convenient data rate buffering; a counter interface matching the control and data signals of a commercial counter to the modules; a control auxiliary con-

taining counters, flip-flop multivibrators, and one-shot multivibrators used in system control; an incremental digital magnetic tape recorder; and special modules providing nonstandard functions unique to an individual system.

The use of a data processor in a real-time data-logging system was investigated for multiparameter experiments in nuclear physics. Assistance in the logical design of input instrumentation, consisting of converters, counters, timers, and buffers, was provided to the NBS Betatron Laboratory, and drawings and wiring tables were prepared. Programming assistance was also furnished in developing routines for handling the input data, preprocessing, output, and the various forms of display. Methods of setting up and modifying the experiments are being considered, including a flexible system for reassigning priorities to four simultaneous experiments.

Information-Processing Systems. A remote inquiry station was designed for the Patent Office to provide easy and rapid communication between human operators, at their respective locations, and a central data processor. The design is such that the locations could be within one building or separated by distances of hundreds or thousands of miles. The remote station design includes a console with a keyboard for encoding messages, a visual display similar to a television picture, means for error correction and control, a local memory, a transmission buffer, and a printer. The design is compatible with the data-logging system requirements anticipated at the Bureau. Alternative data-storage devices were investigated, and magnetostrictive delay lines were selected as meeting all operational requirements.

Assistance was provided in the development, under the sponsorship of the Navy's Bureau of Supplies and Accounts, of an efficient system for the procurement and distribution of the thousands of items within the Naval establishment by controlling their purchase, storage, and distribution. The present and planned functions and requirements of the systems were analyzed, and the characteristics of the equipment needed to be incorporated in the new system were determined. Programs for an interrupt-type of entry into the Newport Supply Depot from Boston were assembled, the availability of suitable equipment was studied, and a minimum system was designed and partially tested. A dial-box entry device was designed and a prototype is being constructed. A system concept for computer operation to intergrate the entire Naval Supply System is under development and points of trade-off between methods of operation and communication loads were noted.

A modest information-handling system was designed for the Naval Intelligence Agency to provide an efficient, low-cost means of storing, searching, and retrieving intelligence data. The design incorporates a modified microfilm camera, an eight-channel keyboard, paper-tape reader and punch for input-output, a viewer modified for printing, a magnetic drum memory, a camera modified for one-to-one microfilm copying, and custom-built plug-in electronic modules. Assistance was also provided in the development of a more efficient coding scheme for indexing the files.

Information handling system designed for the Naval Intelligence Agency as a low-cost means of storing, searching, and retrieving intelligence data. **(See p. 136.)**

The design, development, and construction of ACCESS (Automatic Computer Controlled Electronic Scanning System), a high-capacity, multipurpose data-conversion and data-editing system, were continued. ACCESS is being made under the sponsorship of the Office of Emergency Planning for handling resource evaluation and status information. The system is primarily to gather and prepare data from marked documents; it is an advanced development of the FOSDIC (NBS–Bureau of the Census) and AMOS IV (NBS–Weather Bureau) systems that will, when completed, serve civilian defense needs.

The data processor is designed to control not only the scanner but also communication facilities, pen plotters, and multiple tape units. It performs such operations as table lookup and memory intertransfer, rendering it adaptable for code conversion, verification, editing, reorganizing, screening, control of input-output devices, and preparation of output messages. The central data processor and the flying spot scanner and control of the system are now completely constructed while the plotter system, communication portion, and magnetic tape control unit are designed.

The application of automatic data-processing techniques to processing hydrographic data, from shipboard data logging to the production of charts, was studied for the Coast and Geodetic Survey. Specifications for a data-processing system incorporating a computer and peripheral equipment were prepared for the Survey as the basis for procurement.

The Air Force Systems Command sponsored the beginning of a long-range project to develop plans and specifications for an information-processing and information-control system of a worldwide range for support of future orbital and space programs. Basically, the system must provide means for optimum effective use of instrumentation, communications facilities, and central control, obtaining mechanization of the range "countdown," coordination of instruments at all stations, processing data at remote sites, and controlling the flow of commands and reports in communications links. Preliminary work was conducted, specific problem areas were delineated, and work was begun toward the establishment of absolute time on a global basis

Engineering Applications and Devices. Technical assistance to the Defense Communications Agency was continued to devise and use a computer program simulating the Defense Communications System. The DCS controls a worldwide communication system, a composite of the separate long-line communication systems of the three Services, providing communications for defense and related organizations regularly and during emergency. The Bureau provided consulting services on the performance simulation model of the network being developed by a contractor, and undertook charting the inputs and programs required in the simulations, permitting analysis of vulnerability, recuperability, performance, and economics.

Advisory services were provided to the Bureau of Naval Weapons in connection with its contracts for research in the area of direct digital encoding devices. Two developments were considered: a digital pressure transducer on which assistance was given on the digital logic circuitry and mechanical characteristics of the pressure-sensing elements, and a unique coding device utilizing the varying electric field on a conductive substrate.

A data-logging system for sampling and compiling analog and digital data into a format suitable for transfer onto magnetic tape was extensively modified for the Army's Harry Diamond Laboratories. Analog information can now be transcribed by it onto magnetic tape in IBM format. This equipment is for use in the collection of experimental data throughout the laboratories.

A prototype personnel peer-rating machine, for rapid performance measurements and evaluations of leaders, was designed and a prototype delivered to the Army Personnel Research Office. This machine is now scheduled for comprehensive evaluation at the Army Training Command, Fort Ord, Calif., under actual conditions of use.

The Vigilometer, a versatile laboratory device for presenting audio and visual questions to a human being and recording his responses, was designed and a model is now under development. The system is intended to determine the alertness of the human in a control loop and his fatigue threshold. Detailed engineering specifications were prepared, and fabrication and wiring are more than half completed.

Special Studies and Analyses. Research and development on techniques for scanning serial stereophotographic information were continued

under the sponsorship of the Naval Training Device Center. The object of this program is to use the scanned information for automatically producing three-dimensional terrain information. The input material, in the form of a photograph or other pictorial material up to 9 in. × 9 in., is scanned by an experimental drum scanner linked to an analog-to-digital converter. The magnetic tape output obtained represents each successive 0.005-in. square picture element by one of eight gray-scale levels.

Several test programs for the IBM 7090 computer were written to process the magnetic tape carrying the encoded pictorial data. These programs analyze the digital data and present the information in various ways—spot-by-spot detail, a list of runs, a three-line average, a basic eight-level pictorial printout, experimental four-level and five-level pictorial printouts, and a listing of key trend points.

The Bureau provided consultative services to the Weather Bureau, both in activating Automatic Weather Stations previously developed by the Bureau and in transmitting and processing photographic data transmitted by the new weather satellites of the NIMBUS series. The NBS services included a review of the Weather Bureau data-processing capabilities and an investigation of techniques for producing large photographic cloud history archives.

The U.S. Air Force requested and received assistance in the evaluation of two contractor proposals. One was for the design, manufacture, and installation of a General Purpose Automatic Test System (GPATS) for

Rapid measurements of performance, and evaluations of leaders can be made with this prototype personnel peer-rating machine developed for the Army. **(See p. 138.)**

more effective depot level maintenance of modern airborne electronic systems. The other was for proposed designs for a Versatile Automatic Test Equipment (VATE), to be used in the repair and testing of the Inertial Guidance System, making the most of versatility and standardization of test equipment.

The continuing study of the system requirements for automatic data processing at NASA's Goddard Space Flight Center concentrated on a survey of commercially available magnetic tape-to-tape digital data-transmission systems. Technical advice regarding interconnecting the several NASA computer facilities via high-speed data links was given, including recommendations for microwave transmission equipment and high-speed data terminals.

Management Data Processing. Technical assistance was continued to the Public Housing Administration concerning data-processing techniques and programming for reports on housing applications. The computer programs were revised to reflect the requirements of new legislation concerning the administration of Federal-assisted, low-rent housing. Data about applicants for tenancy in low-rent housing, in addition to data about tenants already in residence, are submitted by the local housing authorities for annual review to determine tenant eligibility. New computer programs were written for processing data on approximately 500,000 reexaminations and 120,000 new tenants annually.

The activities and operations of the Interstate Commerce Commission were analyzed to determine the areas in which the use of automatic data-processing techniques was feasible. Systems and computer programs were designed for applying these techniques to cost-finding studies of motor and rail transportation, for providing information on authorities granted to motor carriers, and for obtaining information on caseloads and the time required for administrative proceedings.

Automatic Mail-Sorting Developments. The Bureau continued its assistance to the Post Office Department's Office of Research and Engineering in applying automatic data-handling techniques and equipment to mail-sorting and route-selection operations. A revised computer program was developed for selecting optimal paths for routing mail, using scheduled transportation links. The new program, designed to aid in a semiannual problem, can handle 84 nodes (airports) and 2000 links (scheduled transportation segments).

A procedure for partitioning transportation networks was developed, in which the network is considered as a graph which can be divided, by the elimination of selected nodes, into several subgraphs having no common points. This demonstrates that a large variety of transportation networks can be partitioned by the elimination of a surprisingly small percentage of the nodes. Work in this area should lead to procedures for determining optimal paths when handling larger networks.

The study of updating files in a codesort system was continued, and an improved procedure developed for updating the incoming file. Programs were written enabling the computer to use these files in preparing standard

Post Office documents.

The network study of the sorting and transportation problem was continued and a mathematical model developed to represent the important properties of a postal transportation network. Further assistance was given to the Post Office Department in the technical monitoring of a large-scale simulation project and human factors study.

2.3.3. INSTRUMENTATION

The Bureau is concerned with both the theory and practice of measurements; its practical work is aimed at improving both industrial technology and the Bureau's own research programs. Since measurement precision depends on the natural limitations of the method and the behavior of practical instruments, both are being investigated to advance the measurement art.

The Bureau maintains an extensive reference file of literature on instruments and measurement methods to help disseminate measurement information and avoid duplicating scientific research effort. The file is designed so that its data can be retrieved partly by mechanical means. Simple techniques insure good coupling between the researcher and the file, so that the researcher is led quickly to relevant information.

Mechanical instrument activities include responsibility for the national standards of humidity and for improvement in standard hygrometers and humidity generators. Calibration methods are being developed for pressure and acceleration transducers, while other mechanical instruments are being developed to meet specific Federal agency needs.

Electrical and electronic methods are widely used in modern instrumentation, even when the initial phenomenon being measured is not electrical in nature. Electronic methods were devised to investigate the characteristics of materials used in vacuum and semiconductor electron devices and the behavior of very high vacuum systems, as well as the characteristics and capabilities of electron devices themselves. Improved electronic instruments were developed not only for use in Bureau research programs but also for use by other Federal agencies.

Failure Anticipation by Semi-Automatic Techniques. For a number of years, the Navy Bureau of Ships has supported an NBS program for developing electronic equipment fault-location techniques. The success of work in the fault-location project led to new thinking on the old idea of a failure-anticipation system, an area demanding of development efforts.

Electronic equipment failures can be anticipated by recording and analyzing equipment performance data. The failure-anticipation methods developed at the Bureau do not employ computer techniques or special interpreting equipment, and thus are relatively simple and versatile. After the recorded data are used for anticipating failures, they can be put to further use in studies of equipment reliability. Such analysis of recorded performance data should permit identification of incipient troubles before they become major problems.

In project FIST, a system for testing and maintaining modularized electronic equipment was developed which requires no more than bulk-changing skill on the part of the maintenance personnel. **(See p. 141.)**

Hall Effect Measurements. The Hall effect, in which a potential is induced by current flow across a magnetic field, was discovered in 1879 but only recently became widely used in electronic instrumentation. The present popularity of Hall devices led the Bureau of Naval Weapons to sponsor a program at the Bureau to establish standard measuring methods and terminology for Hall effect devices.

A proposed standard for Hall generator definitions, terminology, letter symbols, and graphic symbols is in preparation. Included are definitions of linearity error and descriptions of measuring methods. The Bureau joined in organizing a meeting of the American National Committee for the International Electrotechnical Commission (TC 47) to prepare an American proposal for Hall-device standards. The military standard prepared by the Bureau for the Department of the Navy was used as a basis for the American proposal.

Instrumentation using electron paramagnetic resonance to measure small magnetic fields in restricted areas is being developed.

Vacuum Physics. Precise measurement techniques in the very high and ultrahigh vacuum regions are urgently needed, particularly for studies of particle density. The program is now concerned with obtaining more precise measurements of conductance at these low pressures, to make possible better understanding of particle distributions and accurately known conductances to be used as reference standards for ionization gage calibration.

Substitution techniques are being studied for measurement of vacuum flow, since substitution methods are in principle independent of detector charac-

teristics, gas species, and temperature. Successful use of substitution depends upon good detector sensitivity, lack of detector hysteresis, and on calibration and resolution of the variable conductance against which the unknown is compared. A scheme for calibrating the variable conductance against zero-thickness orifices was evolved, and glass rotary valves with specially shaped orifices were produced as variable conductances. Ion gage emission was regulated to 0.1 percent. An experimental vacuum line with these components demonstrated that changes in the variable conductance of 0.1 percent and changes in pressure of less than 0.1 percent at 5×10^{-6} torr can be resolved. This resolution indicates that substitution procedures are feasible.

A Photoelectric Ratio-Measuring System for Incident Light. Measurements of absolute light intensity at selected points are normally subject to the effects of fluctuation of the source during the measurement period. In developing an instrument for measuring the field distribution of bremsstrahlung radiation from a synchrotron, the electronic instrumentation laboratory developed an instrument for measuring the intensity at a fixed point relative to that at another position. The ratio of the two fluctuations originating at the common source must be independent of source fluctuations and must be due to variations in either of the two flux paths.

In the ratio-measuring instrument one phototube was fixed in the light beam and the other mounted behind a slit that could be moved across the beam. The ratio of the measured quantities gave a relative amplitude plot of the radiation beam that was independent of random fluctuations at the source. The light flux arrived at each phototube in the form of pulses. Variable gating circuits allowed independent selection of the measuring interval within the radiation pulse cycle. Ratio measurements were made with a modified strip chart recorder; digital voltmeters also can be used for ratio indications.

A precision electronic integrator was developed as a companion unit to the ratio-measuring instrument for absolute measurement of radiation yield by derivation from a time-integration of photoelectric current. The integrator has a time constant of about 10 days; thus a charge on the integrating capacitor decays at a rate of about 0.5 percent per hour. Linearity as checked with a timer and a digital voltmeter is approximately ±0.01 percent.

Proportional Temperature Controllers. The first work on proportional control of temperature by the Electronic Instrumentation Section was begun in 1947. Since then, 16 different models of temperature-control instruments have been developed for laboratory use within the Bureau. Each new model has represented an improvement in accuracy, dependability, or versatility.

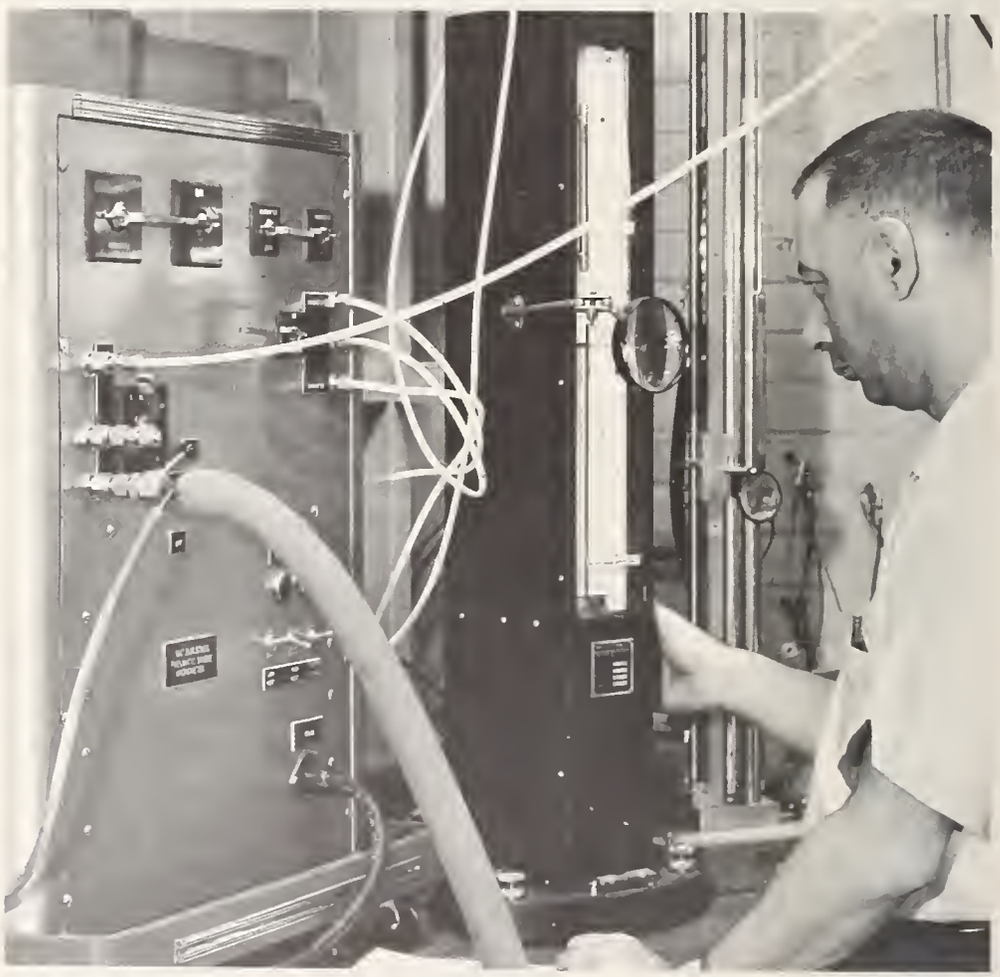
Present systems using resistance thermometers can react to a temperature change as small as ±0.001 deg C to produce a compensating control of heater power. It is possible to increase this sensitivity to differences as small as ±0.0001 deg C. Many systems having high sensitivity react unstably, however, producing a periodic oscillation in temperature. Thermal

time lags in the controlled environment are one source of such instability, so the environment must be designed carefully if high system sensitivity is to be obtained.

Recently designed controllers use thermistors as temperature sensors because of their high sensitivity and low cost. Their electrical stability is questionable, however, so they are currently restricted to applications requiring a control accuracy no better than ± 0.01 deg C. The newer controllers have the advantage of adjusting heating power continuously, as opposed to older systems using on-off, or time-proportional, control.

Replacing vacuum tubes with semiconductor devices made temperature controllers much more reliable. Transistors, for example, operate at lower circuit voltages and with less internal heating. Future work is directed toward even simpler and more reliable designs.

Hygrometry. The Bureau completed the development of a pneumatic bridge hygrometer which is suitable for use as a secondary or laboratory reference standard. This instrument contains four critical-flow nozzles, with a pressure manometer across the bridge, and a desiccant in one branch. The differential pressure across the bridge is a measure of the moisture con-



Pneumatic bridge hygrometer developed for use as a secondary or laboratory reference standard for humidity measurements. **(See p. 144.)**

tent of the test gas flowing through the bridge. The bridge was calibrated against the NBS gravimetric hygrometer; in the range of 0.6 to 19 mg water vapor per gram of dry air, it measures the humidity of the test gas (in terms of mixing ratio) with an accuracy of ± 0.06 percent of full scale.

A preliminary intercomparison between the Bureau's two-pressure humidity generator and the Bureau's gravimetric hygrometer reconfirmed that the generator produces atmospheres of known mixing ratio with an accuracy of ± 0.5 percent or better.

Electromechanical Transducers. The Bureau is engaged in a continuing study of the behavior and performance of electromechanical transducers, particularly pickups sensing such parameters as pressure and acceleration. This program is jointly sponsored by the Bureau of Naval Weapons, the Air Force, and the National Aeronautics and Space Administration.

An experimental technique using shock tube excitation was developed for obtaining the resonances, particularly the lowest one, for a variety of flush-mounted, high-frequency pressure transducers. The technique consists essentially of subjecting the transducer to a pressure step function inside a shock tube. The transducer output is applied simultaneously to an oscilloscope (for a photographic record) and to a magnetic drum recorder. This recorder preserves the transducer's indication for repeated playback into a spectrum analyzer. The analyzer produces a histogram showing the frequency components present in the transient and, roughly, their relative amplitudes.

Selected transducers were calibrated, tested, and evaluated to keep abreast of the newest commercially available pickups and to determine the adequacy of test methods and equipment.

Instrument Reference Service. Industrial and Government scientists developing instruments of any kind must know what has already been done in the same area in order to design without duplication of effort. A scientist seeking information on work already done in his field can make inquiry of the Instrument Reference Service, one of the Bureau's reference and consultation services for scientists.

The Instrument Reference Service enlarged its card index of instrumentation literature by selecting, analyzing, coding, and recording additional information on the special punched cards of the "peek-a-boo" system. Inquiries are answered by means of the index and other information resources.

A number of improvements in the indexing system were made: a simple photographical method of reproducing sets of punched cards was developed. This not only facilitates replication, but the positive and negative copies obtained can be assembled as logical-sum and logical-negation searches. Microcite, the information-searching machine developed at the Bureau several years ago, now is in routine operation performing searches for instrumentation information. An improved machine having a potential search capacity of millions of abstracts is now under development and will be tested in use during the next fiscal year.

2.3.4. RADIO PROPAGATION

The Central Radio Propagation Laboratory (CRPL), located at Boulder, Colo., has the primary responsibility within the U.S. Government for collecting, analyzing, and disseminating information on the propagation of radio waves at all frequencies along the surface of the earth, through the atmosphere, and in space. Some work of the Bureau is international, both in the origin of data and because it is performed in cooperation with scientific groups of other countries. This is particularly true of CRPL's participation in the recent International Geophysical Year (IGY) program and in the International Years of the Quiet Sun (IQSY) program to take place in 1964 and 1965.

IQSY. Several members of the CRPL staff are participating in planning the scientific programs for IQSY. CRPL also prepared the Manual for World Days Program and the International Geophysical Calendars for IQSY. These provide the framework for coordinating many aspects of the scientific programs recommended for each of the IQSY disciplines: meteorology, geomagnetism, aurora, airglow, ionosphere, solar activity, cosmic rays, and aeronomy. The details of these programs call for special observations on certain days during IQSY or special treatment of the data obtained. The rapid communications necessary during the World Days program will be obtained by channeling messages principally through Regional Warning Centers (RWCs). The North Atlantic Radio Warning Service at Fort Belvoir, Va., will serve as the Western Hemisphere RWC, and also as the World Warning Agency responsible for declaring Alerts, days of special geophysical interest.

The World Data Center–A for Airglow and Ionosphere was relocated and plans made for handling the high rate of data inflow which will begin with the IQSY. Microfilming is being considered to improve cataloging and provide rapid availability of data. All incoming data will be immediately copied, and the routine exchange of data made on microfilm. The volume of requests for IGY data has remained high during the past year, indicating the continued need of this service by the scientific community.

IONOSPHERE RESEARCH AND PROPAGATION

The Bureau conducts and coordinates research on the propagation of radio waves as affected by the ionosphere and on the special factors (such as solar flares) which can give rise to large departures from the normal behavior. It is also concerned with research on the nature of the media through which these radio waves are transmitted and the interaction of radio waves with the media. One of the important functions of the Bureau is the preparatiaon of predictions of radio wave propagation and warnings of solar and geophysical disturbances.

Geomagnetic Micropulsations and Infrasonic Pressure Waves. An experiment combining measurements of geomagnetic micropulsations and infrasonic pressure waves was carried out in the auroral zone at Fort Yukon,

Alaska, during August 1962. The results supported the supposition that infrasonic pressure waves having periods of 10 to 110 sec and amplitudes of one to 10 dynes/cm^2 have their source in the auroral region. (For a report on study of infrasonics of other periods.) They are also associated with geomagnetic micropulsations in the same period range, with ionospheric absorption, and with fluctuations of the auroral electrojet. The micropulsation pressure front was found to arrive nightly with a consistent time and directional relationship to the east-to-west progression of the auroral activity maximum. Despite the general relationship, it was not possible to find identical geomagnetic micropulsation and infrasonic excursions. This was interpreted to be a result of reception of infrasonic pressure signals from nonlocal sources, causing the indication of infrasonic activity to precede the local auroral activity in the early evening and to extend later into the morning hours. Variations in the auroral ionospheric heating, initiated by the local electron bombardment, and perhaps through auroral electrojet joule heating fluctuations, seem to be a source of auroral zone infrasonic pressure variations.

These phenomena were investigated by making around-the-clock measurements at Fort Yukon and College, Alaska. Measurements were made at both stations of infrasonics activity index, changes in riometer absorption from the "quiet day" value, variation of magnetic field from quiet day value, and geomagnetic micropulsation activity of period 5 to 30 sec.

Lunar Tide Effect in the D-Region. The presence of a semidiurnal lunar tide in the daytime *D*-region of the ionosphere (at a height of about 70 km) was established for the first time. The lunar tide produces a variation in the height of radio reflection of approximately 0.2 km along VLF radio paths between Panama (Canal Zone) and Boulder (Colo.). A comparable value was obtained for the Hawaii-Boulder path. The maximum height change resulting from the lunar tide occurs two hours before lunar transit. This work was sponsored by the Department of Defense Advanced Research Projects Agency.

Effect of VLF Propagation on Standard Frequency Transmissions. Recently, VLF radio transmissions have been employed in the comparison of standard frequency oscillators separated by great distances, such as between various countries. In applications of this type it is of major importance to determine the errors introduced by the propagation medium. This has been done by measuring the accumulated phase difference between an accurately controlled VLF transmission and a local reference oscillator. It was assumed that any frequency difference between the transmitted VLF signal and the local oscillator, after correction for known frequency changes, increased linearly with frequency. The precision of the frequency comparison was then found to be 4×10^{-10} for observing periods of 1 hour and at least 3×10^{-12} for periods of 300 hours.

If these errors are not due to differences between the oscillators being compared, they must be due to the propagation medium. Thus, the figures

given represent upper limits to the errors introduced by the propagation medium for the particular path being observed.

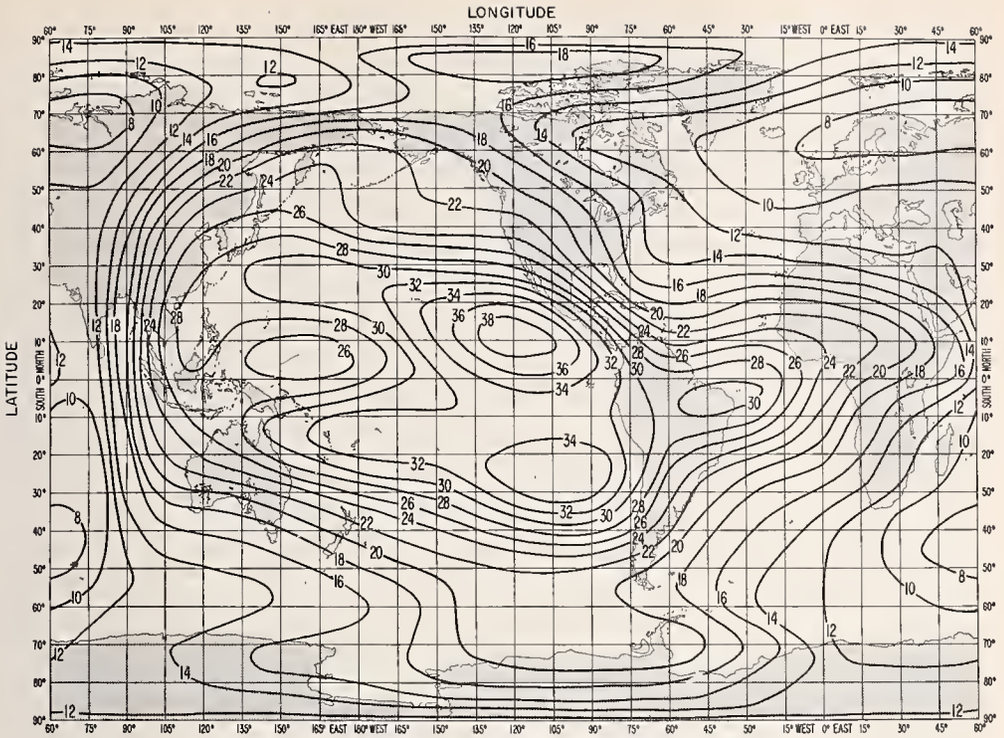
It is interesting to note that the lunar tide mentioned above can introduce appreciable errors in short-term frequency comparisons. The error introduced along the Canal Zone to Boulder path, for example, could be as much as 2×10^{-11} during a 6-hour frequency comparison when the path is sunlit. This work was sponsored by the Department of Defense Advanced Research Projects Agency.

Ionizing Processes in the D-Region of the Ionosphere. Observations of the diurnal phase change on long VLF paths at medium and high latitudes show that the reflection height of the ionosphere drops almost immediately when the lower ionosphere becomes sunlit. It remains at the low level until darkness occurs and then rapidly returns to the nighttime height. Observation at Tucuman, Argentina, of VLF transmission from the Canal Zone over a path crossing the magnetic equator, however, shows a quite different diurnal variation. Near noon the height of reflection shows a dependence on the zenith angle of the sun, averaged over the path. This may confirm suggestions that were made concerning the ionizing influence of cosmic rays in the lower ionosphere. This contribution would be much reduced near the magnetic equator, according to the suggestion, leaving only the effects of the sun's ultraviolet and X-radiation.

It is well known that solar flares produce sudden reductions in the height of reflection of VLF signals during daylight hours. It was recently discovered that nighttime reductions of height also occur in association with magnetic bays. There is a tendency for such events to occur at latitudes where precipitation of electrons from the outer Van Allen radiation belt would be expected.

Ionospheric Predictions by Numerical Mapping. The recently developed Gallet-Jones method of numerical mapping of ionospheric characteristics by modern electronic computer methods was adopted and applied to the CRPL ionospheric radio propagation predictions. For almost 20 years the CRPL Series D prediction charts, prepared by manual and graphical methods, have been standard tools of Government and business communication services in the United States and abroad. The predictions are used in designing communication systems and for frequency planning and allocation purposes, to ensure the most efficient use of high frequencies.

The new series of *CRPL Ionospheric Predictions,* which replaces the former Series D prediction charts, uses numerical prediction maps in two forms. Tables of predicted numerical map coefficients are provided for large users which have computing equipment enabling them to make effective use of the speed and economy of electronic computer methods in applying the predictions to communications problems. The predicted coefficients are also available in punched card form for more efficient computations. World maps of the ionospheric predictions are provided to the small scale user for the manual solution of communications problems. Polar prediction maps also are available for specialized high-latitude applications. Not only



The monthly NBS radio propagation predictions are now being prepared by recently-developed numerical mapping techniques with an electronic computer, and the data is presented in special form for easy input to computer. Graphical prediction maps (*above*, for October 1963) are still provided for users who have no access to a computer. **(See p. 148.)**

are the new predictions believed to be more accurate than the older type, but they are also much more versatile for adaptation to individual problems.

First Topside Sounder Satellite. As a part of an international cooperative program to probe the topside of the ionosphere, the National Aeronautics and Space Administration launched the Alouette topside sounder satellite into a nearly perfect orbit on September 29, 1962. The orbit is inclined 80.5° to the equator and it is almost circular between 995 and 1030 km altitude. The topside sounder was designed and constructed by the Defense Research Telecommunications Establishment (DRTE) of Canada and is controlled by it. It consists of a swept-frequency sounder covering the range of 0.5 to 11.5 Mc/s in 18 sec. The sounder operated perfectly following the launch and since then it has produced more than 400,000 ionograms. Such ionograms show the heights at which downward transmitted signals are reflected by the ionosphere as the signal frequency is swept across its range. The Alouette data are being analyzed jointly in Canada by DRTE, in the United States by CRPL and NASA, and in England by the Radio Research Station at Slough.

The high inclination of the Alouette orbit permits study of the topside of the ionosphere over a very wide range of latitudes from the northern polar region to the southern polar region. Analysis reveals, among other things, a transition from atomic oxygen ions to lighter ions at about 600 km at

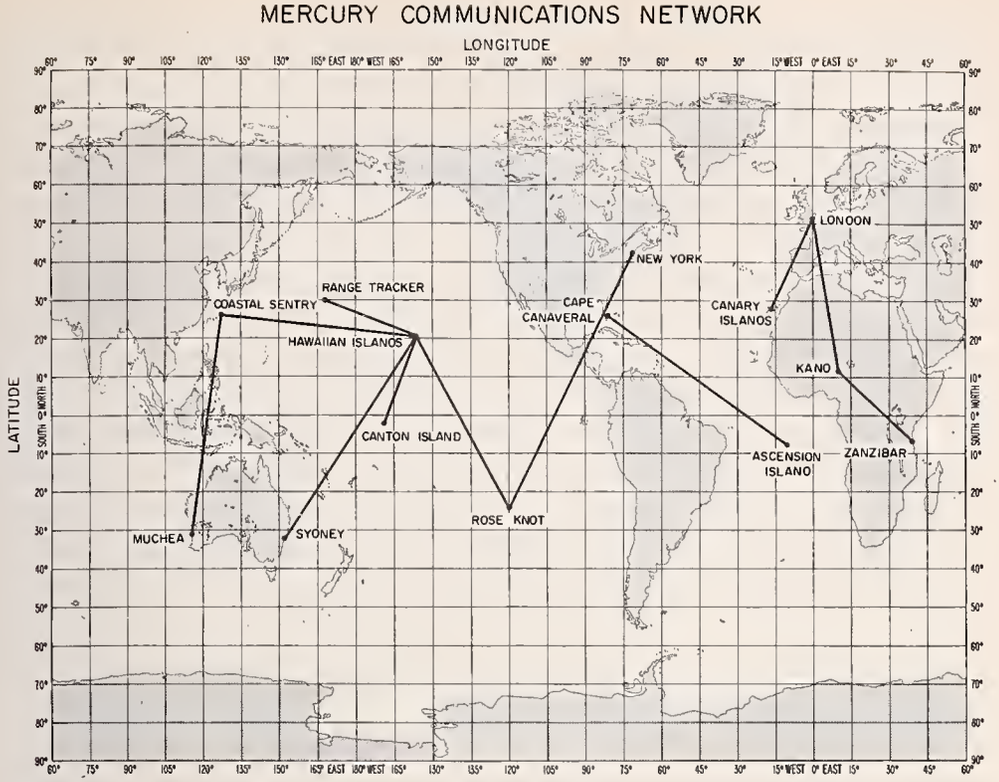
temperate and low latitudes, as well as a tendency for the polar regions to be substantially warmer than the tropics. The topside sounder has observed irregularities in the ionosphere varying in size from a fraction of a kilometer to hundreds of kilometers.

The Central Radio Propagation Laboratory is also involved in a second topside sounder satellite, which has been constructed under NASA contract by Airborne Instruments Laboratory. This instrument, a fixed-frequency sounder operating at six frequencies between 1.5 Mc/s and 7.2 Mc/s, will be operated by CRPL under NASA support. It will be launched by NASA on an improved Scout rocket, into an orbit similar to that of Alouette, early in 1964. Originally set for late 1962, the launch has been delayed several times, both to avoid solar cell damage resulting from the artificial radiation belt created in 1962 and to permit further improvement of the experiment in the light of results from the first topside sounder satellite.

Planetary Ionosphere. Recent theoretical estimates of the composition of the Martian atmosphere, based on 2 percent CO_2 and 98 percent N_2, indicate that the Martian ionosphere occurs at a greater height than does the earth's ionosphere, but at about the same pressure. The maximum electron density for an overhead sun is probably between the density of the terrestrial *E*- and *F*2-layers, that is, between 10^5 and 10^6 electrons per cm^3. There may be, in addition, a layer that absorbs radio waves much more strongly than the normal terrestrial *D*-region.

Assistance to Project Mercury. During the orbital flights of Astronauts Shirra and Cooper, special efforts were made by the staff at the North Atlantic Radio Warning Service located at Ft. Belvoir, Va., to keep Project Mercury headquarters informed of current and anticipated radio propagation conditions. Special forecasts of radio propagation conditions were issued every hour during the flights, specifically for the high-frequency circuits which comprise the Project Mercury ground communications network. The forecasts were made available to the NASA Communications Director and the Propagation Analyst at the Goddard Space Flight Center communications center. During the periods between orbital flights, forecasts were issued by the Warning Service staff weekly, with daily updating as necessary. Reliable forecasts were made possible by associating reports of observed propagation conditions on each Project Mercury circuit with reports of observed solar, geomagnetic, and ionospheric activity occurring at the same time. This work is performed under a Memorandum of Agreement between the National Aeronautics and Space Administration and the Bureau.

The propagation forecasts supplied by the North Atlantic Radio Warning Service enabled the Mercury ground communications center to anticipate problems that might be encountered and select alternative frequencies or circuits to insure unbroken communications. This reliability of communication was required in obtaining information from the astronaut and spacecraft equipment, which was telemetered to the tracking stations and relayed to the Mercury Control Center at Cape Canaveral. The same reliability was required for transmission of decisions from the Mercury Control Center



Special forecasts of radio propagation conditions were issued by the Bureau every 30 minutes during the orbital flights of Astronauts Schirra and Cooper. Such information was essential to effective communications between Mercury control at Cape Canaveral and other Mercury stations around the world. **(See p. 150.)**

to the tracking stations and the capsule itself, to insure the safety of the astronaut and the success of the mission. The staff of the North Atlantic Radio Warning Service received congratulatory telegrams from the National Aeronautics and Space Administration for its role in making the missions successful.

Ionospheric Ray Tracing. Ionospheric ray tracing, which takes the earth's magnetic field into account and allows for a "two-dimensional ionosphere" (one with the horizontal gradients along the great circle path of propagation), is now possible with a new 7090 computer program. This program is basic to an improved understanding of ionospheric propagation, since its output includes step-by-step evaluation of the ray path. It can also be applied to theoretical studies of the phase, amplitude, and frequency of ionospherically propagated radio waves.

This research has been supported partly by the United States Information Agency and partly by the Air Force Cambridge Research Laboratories.

Operation Fish Bowl. During the past year a number of measurements were carried out for the Defense Atomic Support Agency and other agencies in connection with the 1962 series of high-altitude nuclear tests, Operation Fish Bowl. Many complicated technical, logistic, and personnel problems were met and successfully solved on short notice.

Among the variety of support activities, six ionosphere stations were set up and operated and VLF phase measurements were made over a number of paths. Observed perturbations of VLF phase following the blast of July 9, 1962, are attributed to a lowered reflection height in the *D* region of the ionosphere, which produces an advance in the phase of the received signal. Such effects were produced in signals passing through regions illuminated by prompt X-rays from the detonation. Effects observed several thousand kilometers from the detonation probably were associated with the neutron-beta decay process.

Also, the North Pacific Radio Warning Service at Anchorage, Alaska was able to observe unusual effects on high-frequency field strength and on the strength of cosmic noise recorded by a riometer following the shot. The detonation times were announced by telegram to geophysicists throughout the world through the facilities of the World Warning Agency of the International Ursigram and World Days Service. Thus experimenters the world around were able to study their records for effects of the explosion.

On the occasion of the July 9 event, high-frequency signals being received at Anchorage were lost at the instant of the detonation. Recovery began within a few minutes, but 20 minutes later there was again evidence on the records of a further increase in absorption. This second onset was clear on both the riometer recording and the field-strength records. The source of this later absorption is of considerable interest. Analysis of such events should lead to better understanding of processes taking place in the *D*-region of the ionosphere. This work was sponsored by the Department of Defense Advanced Research Projects Agency.

Thermal Properties of the F-Region. Measurements of ionospheric electron distributions at 11 widespread locations during the International Geophysical Year and 1959–1960 have provided valuable data on the solar, seasonal, and diurnal variations of the *F*-region. The temperatures inferred from the curvature of the *F*2-layer peak are uniform at all latitudes in the presunrise period and show a steady diminution with decreasing solar activity. Daytime measurements suggest that the electron temperature exceeds the ion temperature at the height of the *F*2 peak, the ratio T_e/T_i increasing with latitude and in the summer. The work also showed that the high electron densities of the so-called "winter anomaly" of the *F*-region represent, in fact, the normal situation, the summer being the anomalous season because of its abnormally low electron content.

Chemical Release in the Ionosphere. The Bureau participates in a series of experiments sponsored by the Air Force Cambridge Research Laboratories involving the release in the *E*- and *F*-regions of the ionosphere of substances having high chemical reactivity and observing reactions following. In a recent series of such experiments, NBS ionosondes detected the presence of "sporadic-*E*" ionization at the exact level of a strong shear in the neutral wind profile, revealed by viewing a luminous rocket trail, thus confirming a recently developed theory accounting for the formation of

sporadic-*E*. In another experiment, a rocket released 20 kg of sulfur hexafluoride in the daytime *F*-region, producing a large region of reduced electron density through the attachment of electrons to the sulfur hexafluoride molecules. Ionosondes detected this electron "hole" in the ionosphere and showed its growth and ultimate decay over a 30-min period.

Electron Density Measurements in the Ionosphere. New developments, jointly sponsored by the Bureau and the National Aeronautics and Space Administration, in radio soundings of the ionosphere and in precision calculation of electron distributions from these soundings are providing greatly improved detail concerning the structure of the lower *F*-region. By extending downwards the radiofrequency range of the sounding equipments at many of its associated ionosphere observatories, the Bureau hopes soon to be in a position to prepare a worldwide survey of the occurrence of nighttime *E*-region ionization. The measurements also should permit improved identification of the main levels of absorption of solar energy in the atmosphere and will assist study of the influence of the ionosphere on long-distance radio services.

TROPOSPHERE AND SPACE TELECOMMUNICATIONS

Most efficient use of the radiofrequency spectrum is the aim of the Bureau's program in tropospheric propagation and radio noise. Attaining this objective requires a basic understanding of radio wave propagation, noise, and interference. To this end, theoretical and semiempirical prediction methods are developed and compared with statistical samples of data on radio wave propagation and radio noise. As has been the custom, a major part of the effort was carried out in support of the Consultative Committee on International Radio. Several members of the Central Radio Propagation Laboratory staff attended the Xth Plenary Assembly of the CCIR from January 15 to February 15, 1963 in Geneva, Switzerland, in preparation for the International Telecommunications Union Extraordinary Administrative Conference on Space Radiocommunication, including Radio Astronomy, held in Geneva in September 1963.

Reports to the CCIR. A comprehensive report on methods for predicting radio transmission loss at frequencies above 40 Mc/s was presented to the CCIR, and a summary of this report was adopted. These methods were subsequently used to prepare a set of propagation curves for the International Frequency Registration Board to use in its planning for African television broadcasting. A short summary of engineering curves for predicting the absorption of microwaves by oxygen, water vapor, and rain, and for predicting sky noise temperatures was also adopted.

An international working party was set up, under the chairmanship of a CRPL staff member, to examine the theory of figures of merit for a receiving system limited by receiver noise, external noise, or by other unwanted signals and its application to optimum use of the radiofrequency spectrum.

Prediction Methods. A comprehensive report on methods of transmission loss prediction, including a description of the newest methods of calculating service probability, is being prepared. It includes a discussion of theory and comparisons with results obtained by a triple numerical integration. The integral made possible a more adequate investigation of the problem caused by undesired scattering of conventional terrestrial radio signals along the beam of a satellite communication or radio astronomy antenna. Use of the integral also permitted existing predictions of path antenna gain to be updated and generalized.

Electromagnetic Theory. Computer programs were developed for solving diffraction problems by means of the general Fresnel-Kirchhoff theory for diffraction over a single, prefectly absorbing knife-edge, with ground reflected components on either or both sides of the knife-edge. Another computer program, developed for a special case of the general formulation, permits calculation of diffraction over two knife-edges; excellent agreement was obtained with laboratory data at 20 Gc/s.

Prediction of limitations on radio tracking of rocket launch trajectories imposed by the atmosphere was made in further study of the theory of variance spectra associated with radio phase variations on line-of-sight paths.

A study being carried out for the Signal Corps, in connection with the communication problems of an Army in the field, compares the path-to-path variability of transmission loss observed over irregular terrain with a statistical model of terrain profiles. This model depends on the variance spectra of deviations of such a profile from its average slope.

Point-to-Point Moon Communication. An atlas of ground proximity losses and impedances for various antennas was prepared as a guide for planning communications between exploring parties and base installations on the surface of the moon. This makes it possible to determine receiver characteristics required to overcome noise and transmission loss at various distances. Propagation over a sphere having layered ground constants was extensively investigated in this connection.

Radio Meteorology. The direction of research in tropospheric radio propagation focused more attention on the physics of the medium. The effects of the atmosphere on communication frequencies from VHF to the optical range—with emphasis on refraction, scintillation, and scattering—necessitated new basic programs in radio meteorology. The turbulent characteristics of the radio refractive index at microwave frequencies were shown to be chiefly those due to the water vapor of the atmosphere, thus uniting the efforts of the radio scientists and the meteorologist. It was found that information on water vapor turbulence can be roughly correlated with refractive index turbulence. The ease and accuracy of measuring refractive index variations by radio means can be useful in studying water-vapor variations.

Techniques of studying the vertical structure of the atmosphere from ground-based radio detectors are being fully investigated. Experiments include probing the vertical structure of the refractive index by high-powered

radar and passive detection of water vapor from the thermal noise emitted by the water vapor molecule. Passive detection of oxygen, also, would provide a convenient probe of the vertical temperature distribution.

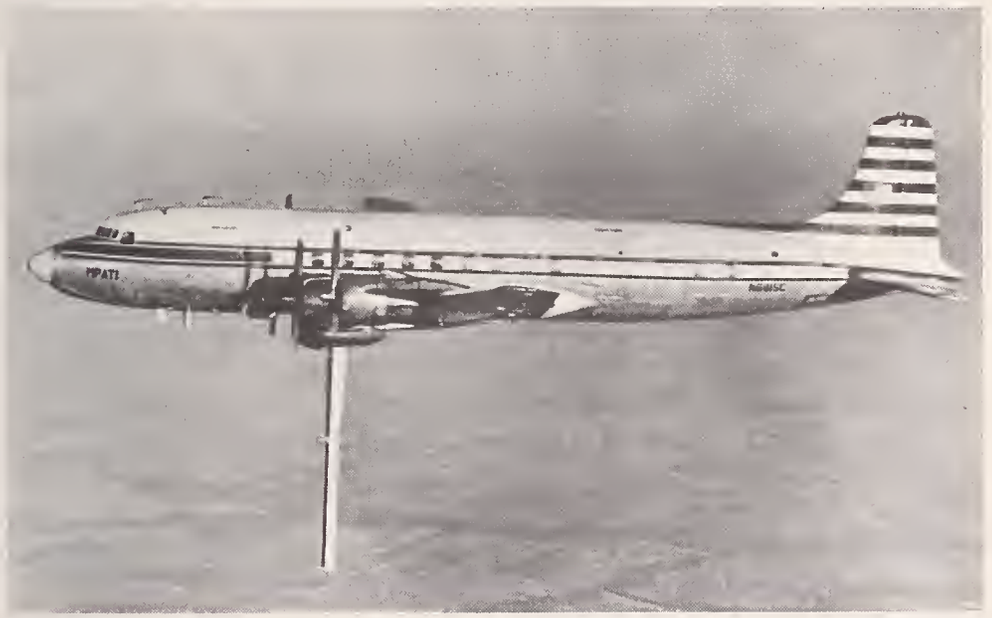
Efficient Television Assignments. The amount of the radio spectrum allocated to television broadcasting is quite large, amounting to about one half of the spectrum below 1000 Mc/s. A recent CRPL study of methods for making television assignments indicates the feasibility of reducing the spacing between cochannel and adjacent-channel stations. Interference effects would be minimized by using precise-carrier offset, alternate transmission polarizations, and receiving antenna directivity.

A sample VHF assignment plan for the United States using reduced spacing indicates the possibility of a twofold increase in the per-channel coverage. The most significant increases would be in the number of areas served by several channels—two or more, three or more, and so on.

Conferences were held between the Bureau and the Federal Communications Commission to explore various problems associated with implementation of the plan, as well as possible courses of action which might be undertaken.

UHF Air-Ground Propagation Tests. Continuous measurements of propagation characteristics for long air-ground paths both within and beyond the line-of-sight were continued during the second transmission year of the Midwest Program on Airborne Television Instruction (MPATI). These measurements provide a unique set of data in that the transmissions emanate from an airplane at an elevation of 23,000 ft in the 800 to 900 Mc/s range.

Although the current MPATI service is for educational television broadcasting, it made possible a great deal of worthwhile information on trans-



High-flying UHF television station broadcasting educational programs over Indiana. Signals are studied by the Bureau to examine variations in transmission loss both within and beyond the radio horizon. **(See p. 155.)**

mission loss variation which has application to many other services employing high terminals, including space-earth propagation.

Refractive Effects in Microwave Distance and Position Measurement Systems. Precision distance and angular position measurements made with systems involving microwave propagation (such as those used in geodetic survey work and in tracking missiles and space vehicles) are subject to errors caused by random fluctuations in the refractive index of the turbulent troposphere. A series of experiments designed to study these distance and angular position errors in long-baseline tracking systems, such as the Air Force Mistram system, was completed. The results include an analysis of the correlation of atmospheric errors on adjacent radio paths, as well as the correlation of distance errors on a single radio path with atmospheric refractive index data.

An experimental study was made of the atmosphere-induced variations in the amplitude and phase of arrival of microwave signals sent over the same low-level line-of-sight path, but at slightly different frequencies. The data analysis included the correlation of phase variations at two frequencies as a function of fluctuation (power spectral) frequency. This work was prompted by the high amplitude and phase stability required in the operation of ground-to-ground calibration and synchronization links in some long-baseline tracking systems. A program was initiated to systematically study the dependence of angular position errors on antenna aperture size and on baseline length and orientation. Experiments are also being conducted for the Army Engineers to study the feasibility of using microwaves in a portable azimuth-measuring system.

Surface-Satellite Communication Interference. In the event that space telecommunications services share frequencies with surface systems, such as point-to-point microwave systems, isolation between terminals of the systems will rely on geographic separation and antenna discrimination. It is possible to make fairly accurate predictions of the service fields of signals propagated through the troposphere, but little is known about the kinds of efficient propagation that occur infrequently and cause serious interference. One source of such interference in the 1 to 10 Gc/s range is expected to be elevated concentration of rain and hail associated with thunderstorms.

An experimental program was undertaken to determine the effects upon space communication system performance of forward scatter interference from thunderstorm cells. Measurements were made at 4.8 and 9.1 Gc/s over a 180-km-wide area of cells and squall lines containing varying amounts of rain, hail, and thunderstorm activity. Signal paths having transmission loss values comparable to those of great circle scatter communications were observed for cells which were off a great circle route. Forward scatter signals were correlated with weather radar data to develop a prediction basis. These measurements will be continued to obtain a reliable basis for appraisals of interference.

Bandwidth of the Tropospheric Propagation Medium. The amount of information that can be sent over a tropospheric radio path is

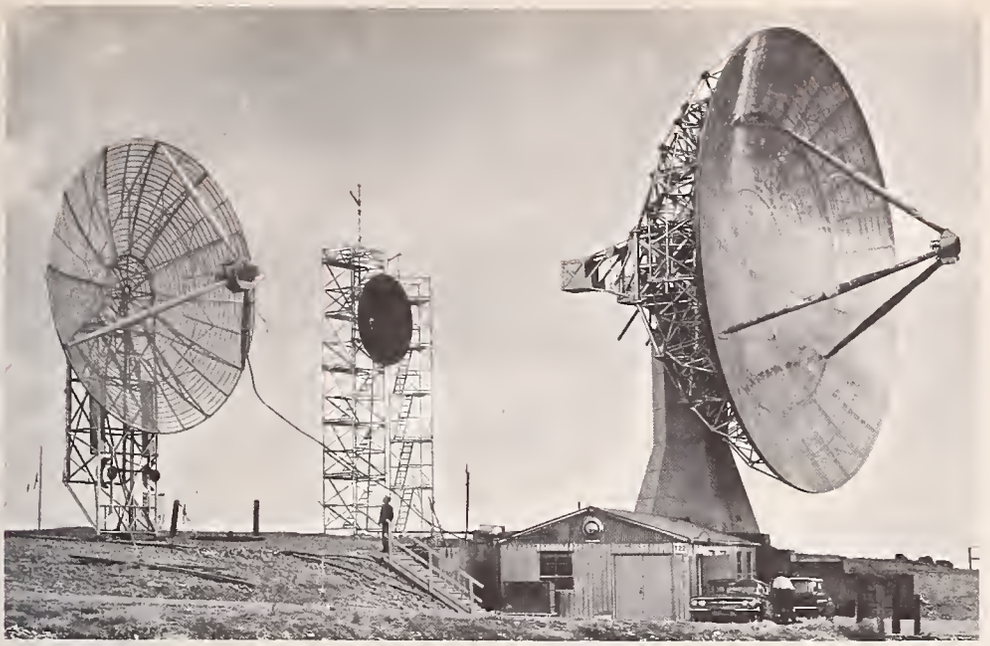


Table Mesa site near Boulder, Colo., showing antennas used in studies of the bandwidth limitation of the tropospheric medium. The data developed will aid in evaluating comunication systems. **(See p. 156.)**

limited by the fading characteristics of the medium itself. The degree to which this limitation is imposed is dependent on may parameters, including distance and type of modulation.

An experimental program was initiated to investigate the relationship between the bandwidth of tropospheric scatter paths and the performance of multichannel, angle-modulated radio transmissions over them. Bandwidth is determined by measuring the coherence of discretely frequency-separated carriers and the performance of multichannel systems in terms of distortion present in the received signal. Previous work indicated that the customary criterion for coherent bandwidth results in a path-bandwidth determination somewhat less than the bandwidth used in successfully operating tropospheric scatter systems. The present program is designed to explore new criteria for coherent bandwidth which will correctly indicate system performance. Frequency dependence is also being considered in the frequency range from 400 Mc/s to 5 Gc/s.

A suitable prediction formula for the performance of tropospheric scatter radio systems is a longstanding need; it is estimated that progess in this area lags transmission loss prediction methods and equipment developments by several years. The path-bandwidth studies in progress will result in the determination of a suitable method for predicting the performance of tropospheric scatter radio systems in terms of voice channel signal-to-noise ratios or telegraph error rates. The limitations due to distortion of multipath propagation through the troposphere will be taken into account. Thus, the present program will result in a substantial contribution to the state of the art of tropospheric scatter systems.

Radio Noise Predictions. Atmospheric radio noise, originating from worldwide thunderstorm activity and propagated via the ionosphere, represents the irreducible interference level with which a signal must compete at a receiver in the high-frequency portion of the spectrum. Accurate prediction of this noise on a worldwide basis is vitally important to users of this portion of the spectrum.

Improved predictions are now being provided by means of corrections to previously prepared CCIR Worldwide Prediction Charts. These corrections were prepared by evaluating data collected in the CRPL worldwide noise-recording network, using several unique electronic computer programs. Besides improving the prediction of noise power, these corrections make possible for the first time predictions of such additional parameters as deviation of the envelope voltage from that producing the average power. Estimates of the reliability of predictions are presented in the form of standard deviations for each parameter.

NBS studies of variability of radio noise over large water areas are carried out aboard the National Science Foundation's Floating Antarctic Research Station, the USNS *Eltanin*. **(See p. 158.)**

Floating Noise Recordings. For the first time, quantitative, objective radio noise measurements were made from a floating radio noise station. These measurements began with the installation of an ARN–2 radio noise recorder aboard the National Science Foundation's Floating Antarctic Research Station, the USNS *Eltanin*. Radio noise data were gathered at eight frequencies between 13 kc/s and 20 Mc/s during the cruises, lasting up to 80 days, made in the last year. The recordings were made primarily from about 40° south latitude to the edge of the Antarctic ice pack, and from about 50° west longitude to about 85° west longitude. From the preliminary analysis of these data, it appears that very interesting information on the variability of the radio noise over large water areas will be obtained.

Automatic Data Analysis Facility. The service provided by its automatic data analysis facility is an important phase of CRPL activities. The data analysis instrumentation center was established to process automatically data recorded on a magnetic tape medium. Playback-to-recorded speed ratios as high as 100 : 1 can be selected to attain extremely rapid data handling.

The data analysis facility provides, in addition to general data translation to put data into a format for use on large scale digital computers, several types of complete analyses by means of special purpose analog and digital systems. These systems operate on the data read directly from the magnetic tape in either direct or the frequency modulation mode. Typical analyses include those of power spectral density, multichannel distribution for amplitude and fading characteristics, continuous auto- and cross-correlation as a function of fixed time lag and averaging time, dynamic autocorrelation yielding an automatic plot of the correlogram as a function of time lag, and other general analog and digital techniques for measuring signal parameters.

Included in this facility also are special instrumentation systems for automatic time-code searching and control of tape, nonlinear function generation, and other automatic data control and conditioning functions.

Instrumentation research associated with the facility has proved to be of great benefit to many outside agencies, as well as to the Bureau.

RADIO SYSTEMS

The Bureau's radio systems program provides technical information on radio propagation factors affecting design and use of radio systems. The emphasis of this work is on long-range radio transmission problems and methods of measurement for radio communication, navigation, timing, detection, and positioning systems. Radio wave propagation studies are carried out for ionospheric, groundwave, and line-of-sight paths to define the limitations, disturbances, and capacity of the transmission medium as a channel. The information obtained is directed toward guidance of engineering practices, allocation and use of radiofrequencies, and evaluation of system capabilities and limitations. Standards and methods of measurement are developed for radio systems to fulfill the needs of federal agencies and industry involved in radio communication operation and regulation. Studies of modulation, antenna design, information theory, and coding are directed toward improvement of the reliability of systems and to the efficient utilization of the radiofrequency spectrum. Consulting and advisory work is done in accordance with the needs of other government, commercial, and scientific agencies.

High-Frequency Ionospheric Radar Research. Radar observations of long distance, high-frequency, backscattered signals are being made to provide needed information about the size, velocity, and direction of motion of ionospheric irregularities and their relationship to HF radar and communication problems. One observing technique, using a new 12 to 25

Mc/s high-resolution azimuthal scanning antenna, permits surveillance of a large area of the ionosphere (of the order of 10^6 sq km projected) with a resolution of about 50 km. Analog signals of the backscatter energy at fixed frequencies are recorded on magnetic tape and then digitized for input to the 7090 computer for analysis. The computer program averages the backscatter amplitude returned from identified cellular units of range and azimuth and subsequently plots it. Variations of the amplitude contours with time provide information about the motions of ionospheric irregularities. An elevation-scanning array operable over the same frequency range has been constructed for use in conjunction with the azimuthal scanning array.

A second technique used in making backscatter observations is that of sweep frequency measurements with either fixed antennas or a rotating log periodic antenna for transmitting and receiving. Ionospheric irregularities are evidenced on the backscatter record as intensification in the signal amplitude over a range of frequencies which changes with time, the amplitude being related to the speed of motion of a focusing irregularity in the ionosphere. An investigation was made, on a limited data sample, into the frequency dependence of the apparent speeds of the irregularities as a function of the observing frequency. This dependence was found to be 37.5 km/hr/Mc/s, with lower speeds being found for the higher observing frequencies. Mean speeds of the irregularities ranged from 900 km/hr at 12.5 Mc/s to 570 km/hr at 22.5 Mc/s.

Preliminary analysis of the spectrum and amplitude distribution of fading HF backscatter signals was begun. The fading spectrum at a given

Erection of an antenna at the NBS Erie (Colo.) field site for radar studies of ionospheric irregularities. **(See p. 159.)**

range contains components of several cycles per second down to a few cycles per hour. The low-frequency components are related directly to the passage of irregularities through the range of observation. Thus the low-frequency components at one range would correlate with those at another range at a different time. An estimate of the velocity of irregularities should be obtainable from this information.

Continuous-wave transmissions of high phase stability at 2.10 Mc/s and 4.055 Mc/s were made on a near-vertical incidence path. Phase-path and group-path data on these transmissions were obtained to ascertain the natural variations imposed upon such signals due to variation of ionization in the ionosphere and motions of irregularities through it. Changes in the phase path of the radio wave are measured by comparing the phase of the wave reflected from the ionosphere with that of the ground wave direct from the transmitter. Recording equipment capable of indicating rapid phase change occurring in time intervals less than a millisecond has shown that Doppler shifts up to 600 c/s occur frequently and last for a few milliseconds. Such Doppler shifts were found to occur more frequently at night and are particularly frequent during spread-*F* conditions. Some of these Doppler shifts are very likely the result of signal reflection from meteor trails.

Solar Flares. Phase-path observations made at times of solar flares have shown that solar flares of optical importance 1^- usually provide sufficient additional ionization below the reflecting point in the *F*-region to be detected by phase changes in the 4.055 Mc/s transmission. Only occasionally does the 2.10 Mc/s transmission, which is reflected from the *E*-region, show identifiable phase changes due to the small flares. The rate of phase-path change for 58 solar flares, measured at 4.055 Mc/s at the time of onset of the radio effects, has shown a median value of about 10 wavelengths per minute. For only 10 percent of the flares observed did the onset phase path change exceed 24 wavelengths per minute. The median duration of phase change resulting from these flares was five minutes. Neither the phase-path rate-of-change nor the duration of the radio disturbance seems to be directly associated with the flare importance.

Modulation Research. Theoretical and experimental studies of modulation, detection, and coding techniques, the characteristics of time-varying propagation media, and their relationships were continued. Experimental studies were made to test the thesis that the limitations imposed on FM transmission by the correlation bandwidth of the medium pertain to the maximum modulating frequency, rather than to the deviation or maximum excursions of radiofrequency. FM communication tests over a 1295-km long, 50 Mc/s ionospheric-scatter circuit were conducted to determine the quality and distortion suffered by signals using various modulation indexes corresponding to deviations from less than to greater than the correlation bandwidth of the medium. Using a number of listeners, hearing tests were made of the recorded voice signals to determine subjectively the quality of the signals for the various modulation indexes. It was found that the quality improved with increasing modulation index and with the frequency deviation well

beyond the 5-to-7 kc/s bandwidth of the medium, as earlier determined by fading correlation measurements.

Theoretical studies of error-detecting and -correcting codes continued with an analysis of a combinatorial problem pertinent to the theory of runs. The solution obtained applies to the decoding of cyclic codes and leads to a particular simply instrumented error-detecting and -correcting decoder. The Department of Electrical Engineering at the University of Colorado completed a study of short error-detecting codes for the Bureau. Theoretical studies were made at the Bureau of the probability of binary errors as a function of average signal-to-noise ratio for a number of modulation techniques subjected to Gaussian noise and a gamma fading model. This model is more comprehensive than the commonly-used Rayleigh model and allows for a variety of short-term fading statistics. Studies were also made of the probability of binary errors as a function of average signal-to-noise ratio for a signal subjected to atmospheric noise and Rayleigh fading. Although atmospheric noise has a considerably different amplitude distribution than Gaussian noise, the study showed the element error probability to be little different than for Gaussian noise when Rayleigh signal fading occurs. Work is being continued to consider other fading models and a variety of modulation-detection techniques.

Digital Errors. Five flexible digital logic equipments were installed: they can be programmed by patch panels to provide a variety of instrumentation quickly and easily for future digital communication experiments. An experimental program was started, using this equipment, to obtain the distribution of digital errors in a high-frequency communication link using frequency-shift keying. Simultaneous oblique soundings of the ionosphere over the same path will be used to relate the error distributions to the propagation conditions. The purpose of the planned experiments is to obtain the information necessary to design more efficient digital error-detecting and -correcting codes for such links.

Testing Facsimile Equipment. The performance of four types of facsimile equipments was measured for the Air Force. A test chart was designed to present recording density, resolution, and legibility. Mechanical and electrical performance of the equipments was measured in back-to-back operation and in long-line operation.

Recording Atmospheric Noise. Evaluation and intercomparison of the performance of radio systems in the presence of atmospheric noise is difficult because the characteristics of the noise are variable in time, making desired or repeatable noise conditions nearly impossible to obtain. A method of overcoming this difficulty is to have a library of atmospheric noise recordings, exhibiting a variety of characteristics that can be used in performance tests. However, conventional tape recording of atmospheric noise is impractical because of the extremely large dynamic range of the noise. For this reason a wide-dynamic-range tape-recording technique for atmospheric noise was developed; it extends the range of a conventional recorder by dividing the noise signal into different amplitude ranges for

recording on separate tape tracks. A dynamic range of 90 db was obtained, using two tracks, over each half-octave bandwidth between 1 kc/s and 25 kc/s and, with frequency conversion, over any 10 kc/s band between 25 kc/s and 500 kc/s. A system obtaining greater dynamic range and bandwidth could probably be developed for more tracks with the use of proper shielding precautions.

Multipath Microwave Transmission. The development of an experimental microwave system was completed for propagation studies in the coming year to determine the bandwidth limitations on multipath propagation of 10-Gc/s signals at several elevation angles. The tests will be conducted by transmitting pulses of one nanosecond duration from a mountaintop to several lower-elevation receiving sites for resolution of path length differentials of one foot or more by use of the short pulses. The objective of the study is to determine if sufficient tropospheric multipath propagation can occur over nonhorizontal paths to limit the information rate that can be transmitted between satellites and earth. Ionospheric effects are expected to be negligible at frequencies above 10 Gc/s.

Antenna Measurements and Research. The principles of electronic antenna scanning developed at the Bureau in 1959–60 were extended to scanning in the elevation plane and applied in the HF ionospheric radar program. A tower 152 meters high was erected on Table Mesa. Ten log-periodic dipole antennas were arrayed along its vertical length at 16-meter intervals, starting at 8 meters above ground. By an application of antenna aperture synthesis it was found possible to improve the aperture efficiency over that attained using uniform amplitude. The improved "illumination" is accompanied by current amplitudes varying sinusoidally with height. The period of the sinusoidal variation determines the angle of departure. Such current distribution results in an enhancement of gain by approximately 3 decibels and a reduction of the main beamwidth by a factor of 2. The above comparison is with the same antenna having uniform amplitude illumination and phase advanced (or retarded) uniformly by an amount proportional to height.

The antenna was erected next to the horizontal array of 25 log-periodic antennas electronically scanned in azimuth, and is intended to supplement it. Both operate in the band of 12 to 25 Mc/s and have been designed for HF ionospheric propagation studies.

Computer Program for Radiation Patterns. A computer program was prepared to determine radiation patterns of curtain arrays for the Voice of America. The program was made as general as possible, allowing for such variations as in the number of bays and elements stacked one above the other. It presents both the horizontally and vertically polarized fields as well as the composite power pattern.

Progress was made in applying antenna aperture synthesis to the analysis of complex electromagnetic fields. A computer program was designed to evaluate the components of plane wave fields from measured field amplitude and phase distributions. Strength, polarization, phase, and direction are

Azimuthal and elevation electronically-scanned arrays at the NBS Table Mesa (Colo.) field site are used in high-frequency ionospheric propagation studies. **(See p. 163.)**

obtained for each of the several component sources of the field. The program was tested, using simulated field measurements obtained from assumed components; the component values were accurately reproduced in the test computation. Experimentally obtained data likewise were reduced to original components closely approximating known values.

Frequency Utilization. Services for the computation of HF radio path performance, with emphasis on the selection of optimum frequencies, were expanded through the development of faster and more comprehensive computer programs. Research into improved methods of predicting HF radio system performance, using ionospheric data, radio noise data, service requirements, and antenna and modulation information, paralleled the development of computer programs.

Services using computers to predict HF radio system performance are divided between the routine prediction and special studies. Examples of routine predictions are those for operation of the ground communication complex of the NASA communication system and for monthly predictions for the wire news services. Numerous special studies were devoted to problems such as the long-range planning of NASA and VOA facilities and the Bureau's consideration of relocating standard frequency station WWV. In connection with development of U.S. policy concerning frequency usage within the United States, reports were prepared to summarize the technical considerations in the selection of optimum frequencies for space communication systems and for HF communication systems.

Radio Navigation Research—Low-Frequency Loran. Through a unique program involving several agencies, extensive low-frequency ionospheric radio propagation data have been obtained at very nominal cost. This was done in a cooperative program cosponsored by the Bureau, the Coast Guard, and the Advanced Research Projects Agency of the Department of Defense. Since the Loran-C radio navigation system uses ground-wave transmissions at LF (100 kc/s), several Loran-C stations were asked to participate in obtaining propagation data. Existing standby equipment was slightly modified to make reciprocal measurements of the singly-reflected ionospheric signal over two paths. The paths, a high-latitude path in the Aleutian Islands and a low-latitude one in the mid-Pacific, were chosen because of special interest in these regions during high-altitude nuclear tests.

Preliminary analysis of the year's data obtained from the Loran-C operation over the high-latitude path indicates many interesting and unusual phenomena. Phase and amplitude readings taken every 15 minutes at each end of a reciprocal path have been analyzed and the known phase and amplitude of the ground-wave vector removed at each data point to obtain the uncontaminated, singly-reflected, ionospherically-propagated primary signal.

For departure from mean values there was very poor correlation between phase and amplitude changes at all times; the correlation was calculated to be less than 0.2 for the entire year. The correlation between phase changes observed at the two ends of the reciprocal path was approximately 0.6 for a year's data.

In a separate study involving fast phase changes occurring at the two ends of the path, only one out of three changes was seen simultaneously at both ends of the path. The correlation coefficients for the amplitude fluctuations on the reciprocal path range from 0.6 to 0.7 during the day to less than 0.1 during the night.

The standard deviations of both the phase and the amplitude data were higher during the winter than during the summer, and higher during the night than during the day for both winter and summer. In general, the amplitude fluctuations demonstrate poorer reciprocity than do the phase fluctuations, and both demonstrate poorer reciprocity at night than during the day. Another interesting observation is that both the phase and amplitude fluctuations exhibit nonreciprocity at times.

Applied Electromagnetic Theory at Frequencies Below 300 kc/s. A theoretical problem of propagating an electromagnetic pulse via composite ground and ionospheric waves was solved for propagation in the waveguide between the ionosphere and the ground, for long wavelengths (over 1000 m). This required the construction of suitable transfer functions for both the ground wave and the ionospheric wave. The concept of continuous stratification of the lower ionosphere and arbitrary, constant magnetic field was introduced into the solution, so that the form of the lower boundary of the ionosphere with respect to altitude could be taken into account as a profile of electron density-altitude, $N(h)$, and collision frequency-altitude, $\nu(h)$. Collision frequencies proportional to the thermal energy of the gas were introduced into the analysis with the aid of a complex collision frequency parameter in the Langevin equation of motion of an electron gas. This parameter was found to be frequency-dependent and characterized by three frequencies: ω, $\omega \pm \omega_H$ where $f = \omega/2\pi$ is the frequency under consideration and $f_H = \omega_H/2\pi$ is the gyrofrequency of the electrons.

The residue and zonal harmonic methods for the computation of LF, VLF, and ELF radio fields were extended to take account of an anisotropic ionosphere. These methods were introduced as a rigorous supplement to the geometric-optical theory.

Thus, the exact solution to the problem of propagation of terrestrial radio waves around a sphere having a concentric ionosphere can be represented theoretically as a notoriously slowly converging series of zonal harmonics. Nonetheless, the advent of large-scale computers makes this classical, apparently intractable, solution quite practical at frequencies less than 30 kc/s. The rigorous residue methods which were also developed in considerable detail on the large-scale computer offer a highly convergent representation of the exact solution. It is interesting to note, however, that the zonal harmonics method is still competitive at frequencies less than 30 kc/s, since the search for residues in complex Riemann surfaces is difficult to program reliably for a computer over a wide frequency range. Furthermore, the zonal harmonics were found to be an independent numerical check in practice, since this method gives the same answers, by definition, as obtained using the Cauchy residue theorem. A detailed study was made of all approximations employed to introduce the effects of anisotropy of the ionosphere into the theory of propagation; computer programs were devised to calculate the field under a variety of circumstances.

An extensive program to interpret the Loran-C radio navigation-timing pulse measurements with the aid of the theory of propagation described was begun and methods studied for testing various profiles or models of the lower ionosphere under the variety of specific experimental conditions offered by Loran-C. Models were proposed for various times of the day and various latitudes. In general a considerable knowledge of the lower ionosphere was gained by application of the theory to experiment. Further, it was found that such combined effort prompted further research to improve the theory of propagation.

Optical Communications Studies. A limited study program on laser systems was initiated to investigate the propagation of coherent optical (infrared and submillimeter wave) radiation through the atmosphere to provide information on short-term fading and angular scintillation for communication channel characterization. A helium-neon cw laser will be used initially for a radiation source and transmission from Pikes Peak to Boulder is now being carried on. Microwave and meteorological measurements for this path will be obtained and the laser data will be analyzed and correlated with the measurements.

UPPER ATMOSPHERE AND SPACE PHYSICS

Knowledge of the atmospheric medium is a prerequisite to the understanding of the propagation of radio waves through this medium. This knowledge is also essential in a host of applications in addition to radio communication. The program of upper atmosphere studies is conducted using three experimental approaches in addition to theoretical studies. The experimental approaches are (1) ground-based geophysical observations, (2) satellite observations, and (3) laboratory experiments simulating atmospheric processes.

Jicamarca Radar Observatory. At the Jicamarca Radar Observatory, located on the magnetic equator near Lima, Peru, studies are being made of various features of the equatorial ionosphere with a powerful radar at 50 Mc/s. Its basic function is to study the distribution of electron density for heights to 10,000 km or more above the earth's surface by means of the incoherent scatter technique. Other parameters of the ionosphere, such as electron and ion temperatures, are also being measured.

It was recently discovered at Jicamarca that ion gyrations, which were expected to affect the incoherent scatter signal, were not detectable. This result has now been explained on theoretical grounds. Thus, the use of the Jicamarca radar as a ground-based mass-spectrometer will now depend upon other characteristics of the incoherent scatter spectrum.

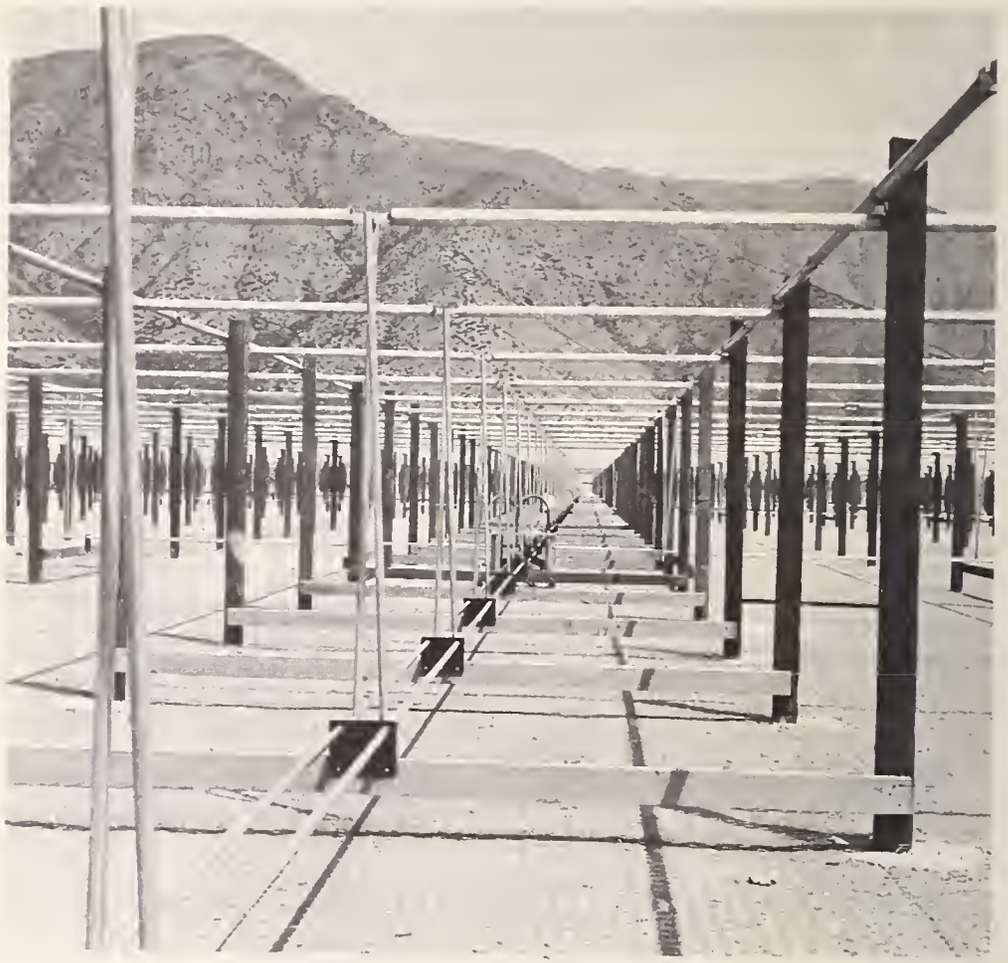
The Jicamarca radar has been operating at full capability for incoherent scatter studies since December 1962. Since that time incoherent scatter observations have been limited to tests aimed at confirming theoretical predictions of the influence of the ion and electron temperatures. This has been necessary, inasmuch as some difficulty is experienced in measuring electron density accurately in regions where more than one ion species is present in significant concentration. The preliminary tests are nearing completion and it is hoped that semiroutine measurements of electron density versus height, as well as ion and electron temperatures versus height, will soon begin.

The extremely high radar sensitivity available at Jicamarca enabled the detection of radar echoes from Venus when the planet was observable from Lima during the first week of December 1962. Both short (1/2000th of a second) and long (3/1000th of a second) pulses were transmitted. Echoes from the long pulses often were at a level four times the background noise. Practically no pulse-spreading was observed, indicating that the

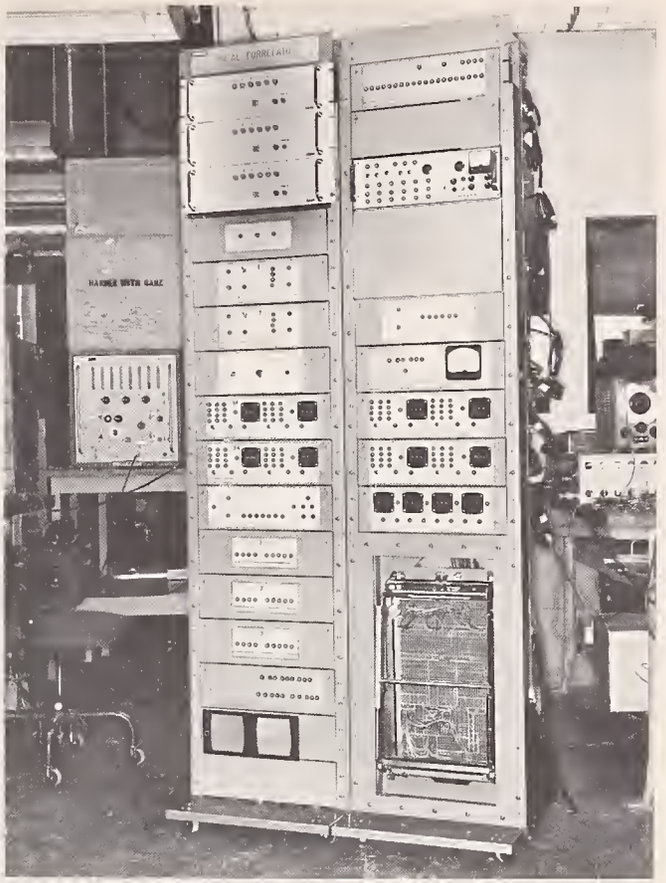
surfacc of Vcnus is considerably smoother than that of the moon.

From observations of the synchrotron radio noise emitted by trapped electrons resulting from the July 9, 1962 nuclear explosion, a fairly accurate description of the energy distribution of the electrons was made. The decay rate of the artificial radiation belt was observed and is the subject of continuing study.

The equatorial electrojet is one of the equatorial phenomena being studied at Jicamarca. This is a strong daytime current stream flowing in the ionosphere at a height 100 km above the magnetic equator. Radar echoes obtained from irregularities in the electrojet led to the theoretical explanation that the irregularities are produced by a "two-stream" plasma instability in the electrojet current. The theoretical and experimental results are completely consistent in the electrojet case, and the implication is that the same interpretation can account for similar irregularities observable in the aurora. The results obtained at Jicamarca form one of the first instances in which theoretical predictions regarding plasma irregularities were confirmed experimentally with good precision.



The 22-acre radar antenna of the Jicamarca Radar Observatory near Lima, Peru, was recently used for studies of the planet Venus and the equatorial electrojet in addition to its regular functions in measuring parameters of the ionosphere. **(See p. 167.)**



Digital correlator and control system for the Jicamarca Radar Observatory near Lima, Peru, provides for more efficient use of the radar and analyses of the received signals. **(See p. 169.)**

Digital Control and Correlation System for the Jicamarca Radar Observatory. The Jicamarca radar is used to measure the characteristics of the ionization in the ionosphere and exosphere. Since the reflected radar signals are often very weak, special detection methods must be used to extract the desired signals from the noise background. A new device for doing this was recently installed at the radar site. This device, called a digital correlator, is actually an interconnected set of timing and signal-processing modules which forms a complete control and detection system for the radar.

Individual modules of the system include voltage-to-digital converters, a magnetic-core buffer, a multiplier, a pulse-height analyzer modified to serve as a multichannel accumulator, and a variety of pulse-generating and switching units. The sequence of events occurring in an experiment is determined by a module called a programmed controller, which controls the sequence in which other modules perform such functions as radar pulsing, observing the reflected radar signals, storing the received signals, and computing correlation coefficients.

The entire system of digital correlator modules and the radar is electrically interconnected through a removable plugboard. An experiment can be set up in a relatively short time by placing a plugboard, which has been prewired to perform the functions of a particular experiment, in the plugboard receiver. By this means, within a few minutes after an unusual

ionospheric or exospheric phenomenon occurs, an experiment designed to observe that phenomenon can be in operation or an existing experiment modified to make special observations. The result of having the correlator in use is that better, more rapid, and more numerous observations and experiments are made possible.

Studies at Magnetically Conjugate Points. Following the successful pilot conjugate point experiment conducted during the Antarctic summer of 1961–62, a more ambitious operation was organized, supported in part by the National Science Foundation, to run through 1963 and extend into the IQSY.

The concept of conjugate-point studies is that observations made at opposite ends of a given line of the geomagnetic field permit the investigation of geophysical phenomena which are propagated along the field. The pilot experiment used just one pair of stations and therefore gathered data on phenomena occurring on just one geomagnetic field-line ($L=4$). The new program includes three conjugate pairs: Antarctic stations South Pole ($L=13$), Byrd ($L=7\frac{1}{2}$), and Eights ($L=4$) are paired with corresponding Canadian stations at Frobisher Bay, Great Whale River, and Baie St. Paul. The data will be obtained from latitudes greater than, equal to, and less than that of the auroral zone maximum.

A variety of instruments, including the riometer, VLF receiver, micropulsation equipment, and magnetometer, is in use at the conjugate stations. The wealth of new data being obtained will be applied to test and extend the preliminary results obtained previously. It is already apparent that many of the absorption events measured with riometers are of different intensity in the two hemispheres, and there are indications that significant time delays exist between some conjugate events. Although many events correlate very well, some are observed in only one hemisphere. When full data become available from the Antarctic, a more complete analysis of the occurrence. structure, scale, and movement of absorption events will be possible. Valuable data are being gathered about VLF emissions, both discrete and continuous. The wide range of techniques now in use will make for interesting interdisciplinary comparisons.

Continuous Observations of VLF Emissions. VLF emissions have been observed continuously since May 1961 and recorded continuously at several locations. Because of the low time resolution of the instrument it was possible for the first time to pick up VLF pulsations having periods of 20 to 300 seconds. These periods are in the same time range as micropulsations and some X-ray events; the possible connection between these two phenomena and VLF events is being studied.

VLF Emissions and Whistlers at Conjugate Points. The Bureau started its program of systematic observations at magnetically conjugate points in 1961. Whistlers echoing between the hemispheres were observed as early as 1956, but only a few observations of VLF emissions at conjugate points have been reported. The results from the conjugate point stations reveal several patterns.

VLF emission events which last for several minutes to several hours are seen simultaneously at conjugate points. When these same events are examined in detail, it is found that the separate discrete emissions which make up the total event alternate between the hemispheres. This alternance may be due to echoing of the VLF wave, or re-emission of the wave.

Electron Densities in the Lower Ionosphere. The *D*-region and its physical and chemical properties are of interest from the practical viewpoint because of the disruptive effects the *D*-region can have on long-range radio transmissions. The *D*-region is of great scientific interest also because it is the region where energetic particles of extraterrestrial origin interact with the atmosphere. However, the *D*-region is at a particularly difficult height (40 to 90 km) to study directly because the atmospheric density is too great for satellites to orbit in it and too small to support high-altitude balloons. Therefore it must be studied by rockets (which remain in the region only minutes) or by ground-based techniques. The latter have the advantage of continuous operation.

An observational program was conducted to measure the auroral-zone absorption of cosmic radio noise as a function of frequency. By means of refined experimental techniques and the development of a special computer program, it is possible to interpret these data in terms of the height profile of electron density in the *D*-region. Such profiles have been deduced for polar-cap absorption events and for some types of auroral events. The analysis is continuing, and should provide valuable information about the physical and chemical processes of the *D*-region.

This research is supported in part by the Advanced Research Projects Agency.

Auroral Absorption. Radio propagation in the HF and lower VHF bands at high latitudes is characterized by the frequent occurrence of strong absorption which is often extremely variable in both time and space. This absorption occurs in general association with aurora and magnetic disturbance and has become known as "auroral absorption" to distinguish it from the less common "polar-cap absorption" associated with the influx of solar cosmic rays. Auroral absorption displays several mysterious features; a theoretical investigation of particle bombardment processes in the upper atmosphere has been started, with the ultimate aim of explaining some of these features. In particular, the role of high-temperature electrons in producing some of the observed effects is being considered. When an electron is freshly produced by ionization, its energy may be several hundred electron-volts, corresponding to an extremely high effective "temperature." This energy is eventually lost through collisions with atmospheric atoms and molecules, but during this process the collision frequency is very high so that the energetic component of the electrons may contribute appreciably to radio-wave absorption. A further raising of electron temperature, and hence collision frequency, may be due to electric fields in the ionosphere; this point is being investigated.

Absolute Calibration of Airglow Photometers. Two problems arise in connection with the calibration of night airglow photometers: the light level is near the low end of eye visibility, and the large field of view customarily used makes it difficult to use point sources of light.

The intercalibration of photometers on a national and international basis is of particular importance. It is estimated that the spread of uncertainty among the calibrations of the 28 airglow stations participating in the IGY is probably contained within ± 20 percent. A spread of such magnitude ruled out the possibility of making detailed studies and interpretations in a synoptic sense.

The Fritz Peak Observatory set up a calibration laboratory in preparation for the IQSY. The primary standard is a blackbody which illuminates a magnesium oxide screen. Secondary portable standards have been developed, using a mixture of two phosphorescent materials in which C_{14} has been embedded. The spectral emission covers the range from the N_2^+ band at 3914 Å to the red oxygen line at 6300 Å. Intercalibration between the Fritz Peak standards and those of other airglow observers will be encouraged in the hope that a significant improvement will be achieved during the IQSY.

Mid-Latitude Red Arcs. The occurrence of so-called mid-latitude red arcs, well-defined bands of atomic oxygen 6300 Å red line emission along restricted geomagnetic latitudes between the auroral and equatorial zones, has been observed at various times in the past few years. A promising model now developed attributes the red arc excitation mechanism to electric fields present in the ionosphere. The detailed calculations agree with the observed properties of the mid-latitude red arcs as well as with the accompanying geophysical manifestations of red arc occurrence. These calculations utilize techniques previously developed at the Bureau for computing electron energy distribution functions of atmospheric gases in the presence of electric and magnetic fields. This model is of great interest as it suggests a connection between the red arc occurrence and the physics of the magnetosphere where the electric field is probably generated, possibly by the solar wind impinging on the earth's magnetic boundary.

Studies of Ionospheric Irregularities. Irregularities in electron density of the ionosphere can be revealed by study of the periodic fading of radio signals from artificial satellites and cosmic radio sources. An analysis of irregularities that vary from 50 to 400 km in the horizontal direction revealed that they occur mostly at night, show no seasonal variations, and decrease in density with increasing magnetic activity. They also appear to be distributed throughout the ionosphere. Observations made simultaneously at three stations in a line parallel to the satellite path enabled a vertical cross-section of the ionospheric irregularities to be obtained. Such a profile is like a "snapshot," because of the high velocity of the satellite.

A satellite scheduled for launch during the latter half of 1963 is to carry an ionospheric beacon transmitter that will enable a new and more accurate analysis technique to be used. The accuracy of spaced station observations

will be improved, in addition, by equipment being built to utilize a new receiving technique combined with telemetry to a central station. The resulting vertical profiles should reveal the changes of size and shape of irregularities with relation to such factors as time of day and magnetic activity, and perhaps serve as a basis for rejecting or accepting theories of their origin. An ionospheric beacon transmitter has been designed and is being procured for another satellite, which will have a highly eccentric orbit so that the measurement of electron densities far above the ionosphere can be attempted. All of this work is supported by the National Aeronautics and Space Administration.

Such irregularities can also be studied by observation of the bending of radio waves that pass through them. Cosmic radio sources are being observed to analyze this bending in a cooperative experiment using a large radio telescope, at Clark Lake, Calif., built and maintained by General Dynamics/Astronautics. Because the apparent motion of cosmic sources is but a fraction of that of a satellite, the motion of the irregularities themselves is being studied by this technique.

The bending of radio waves caused by small-scale irregularities, 1 to 2 km in the horizontal direction, produces what are called scintillations in radio signals. Observations of satellite scintillations verified that the height and intensity of small-scale irregularities increases to the north and that differences in geographical distribution are related to sunspot activity. This work was supported by the United States Air Force.

Theoretical Studies of the Outermost Atmosphere. Plasma thrown out by the sun and impinging on the earth's magnetic field from time to time produces magnetic disturbances ("magnetic storms"), precipitation of energetic particles into the ionosphere, occurrence of auroras, and disturbance of ionospheric radio communication. The mechanisms relating these phenomena to each other are, however, not yet fully understood. Theoretical calculations have been made of the interaction of such solar plasma with the outer portions of the earth's magnetic field. These calculations show that the boundary region between the plasma and the magnetic field lies closer to the earth on the night side than was earlier presumed to be the case, but is farther from the earth in the polar regions than had been presumed. This latter conclusion is of particular significance in evaluating mechanisms theorized for the solar plasma reaching and disturbing the ionosphere. Calculations are continuing on the amount of magnetic field disturbance associated with variations in the solar plasma, and the consequent displacement of conjugate points, connected by a magnetic field line on the earth's surface, which have special radio disturbance properties.

Recent satellite measurements greatly extended our knowledge of physical conditions in the outermost reaches of the earth's magnetic field. They have shown, in particular, that in the general direction of the sun the magnetic boundary region is usually found at a distance of 40,000 to 64,000 km from the earth's surface, and that the trapped particles of the outer Van Allen belt often extend out as far as this boundary. The behavior of these outer-

most trapped particles is believed to be of considerable importance in connection with auroras and magnetic storms; for this reason a theoretical investigation of their drift motions was carried out recently. It was shown that particles which become trapped in the outermost part of the geomagnetic field tend to be concentrated into a relatively narrow belt, because of the distorted nature of the field, as they drift from the sunward side of the earth to the dark side. Also, a magnetic storm should have the effect of concentrating preexisting trapped particles into similar belts, which can persist after the storm has ended. Narrow belts of trapped particles of this type were observed by satellites during magnetic storms. Their existence may have a direct bearing on the production of the long, narrow arcs of luminosity often associated with the aurora.

Cyclotron Resonance in Slightly Ionized Gases. A detailed analysis of the line shape and width of electron cyclotron resonance absorption has been carried out. At cyclotron resonance, i.e., the gyration frequency of an electron in a magnetic field, the cyclotron orbits in a weakly ionized gas are interrupted by electron-neutral collisions, thereby determining the absorption-line width and shape. Analysis of the width and shape is quite complicated for many real gases due to the velocity dependence of the electron-neutral elastic collision cross section.

The problem has been solved for various analytical representations of the velocity-dependent cross sections using various electron energy distribution functions. The problem was also solved for argon and nitrogen, using experimentally determined cross sections and a Maxwellian electron distribution. The extreme importance certain minor impurities could have on band shape was demonstrated theoretically.

Space Resolved Afterglows. Studies of the space resolved "afterglow" in a fast-flowing helium discharge system were carried out by means of emission and absorption spectroscopy. The afterglow technique is being developed because of its possible use in studying chemical and electronic reactions where the reactants (and electrons) are thermalized at essentially room temperature. In the helium case the afterglow shows a very high molecular-to-atomic emission intensity ratio relative to an active discharge, a phenomenon as yet not understood. The density of both singlet and triplet metastable helium atoms was found to increase somewhat in the helium afterglow region. The diagnosis of the helium afterglow is being extended and other systems are being investigated by the flowing afterglow technique.

Infrared Spectra of Charge Transfer Complexes. A comprehensive and novel theory of the infrared spectra of weak charge transfer complexes was developed. These complexes are formed by transfer of electrons from donors to acceptors; it was shown that the infrared absorption characteristic of such a complex must be due to variation in the charge transfer. This variation is a consequence of molecular vibration. Two specific mechanisms are proposed for the variation and selection rules derived. The large amount of data available on aromatic-halogen complexes is well explained by this theory. A solution was proposed to a longstanding ambigu-

ity concerning the geometry of benzene-halogen complexes. The geometry is of great significance for the theoretical understanding of the quantum mechanical molecular description of such compounds.

Infrared Spectroscopy of the Atmosphere. The Bureau's Consultant in Physics of the Atmosphere conducted a continuing study of the atmosphere by means of spectroscopic observations. In order to compute the transmission of infrared radiation through the earth's atmosphere it is necessary to know the atmospheric spectrum in absolute detail Atmospheric transmission is primarily dependent on absorption and re-emission by water vapor, carbon dioxide, and ozone. The computation of atmospheric transmission was accomplished by a computer, using as input data the positions, experimentally known strengths, and half-widths of 4400 specific lines for transmission through water vapor. The 3.5μ (2857 cm^{-1}) to 2.25μ (4444 cm^{-1}) portion of the spectrum used falls within the nonvisible infrared region.

The transmission of the atmosphere is computed from the line positions, strengths, and half-widths, using Beer's Law and a Lorentz line-shape profile. The absorption is computed at any given frequency as the sum of the wing absorption of all the lines and the profile structure of an individual line if the frequency position is near a line center. These theoretical absorption spectra are then degraded, using a slit function, in order to compute spectra which are comparable to observed spectra. Comparisons with high-altitude spectra obtained from aircraft by the Canadians and by the British give excellent agreement with every detail in the water vapor spectrum.

An atlas of computed spectra for the 2.7 μ water vapor transmission has been prepared. The absorption lines due to water vapor in the 1.1-, 1.4-, 1.9-, and 6.3-μ bands are being compiled. The positions, strengths, and half-widths of the CO_2 absorption lines are also under preparation. This theoretical analysis is being conducted under the sponsorship of the Advanced Research Projects Agency. The results of the calculations will be applied to atmospheric radiative transfer problems.

ELECTROMAGNETIC RESEARCH

A number of theoretical studies conducted by the Consultant on Radio Wave Propagation fall loosely into the category of electromagnetic research. Supported by the Bureau, the Air Force Cambridge Research Laboratories, and the Department of Defense Advanced Research Projects Agency, these seemingly unrelated studies used methods having much in common. Some of the accomplishments in this area during Fiscal Year 1963 are described below.

Resonant Characteristics of a Corrugated Sphere. The radiation from a radial electric dipole on the surface of a corrugated sphere was examined. It was shown that the power radiated in a given mode depends critically on the surface reactance and the circumference of the sphere. In fact, for certain values of these parameters, particular modes are strongly excited and contain most of the power. Such a structure can be regarded

as an external resonator having resonant characteristics that are a function of the refractive index of the surrounding medium. This opens the possibility that a surface-wave spherical resonator may have important applications to refractometry.

Influence of a Sector Ground Screen on the Field of a Vertical Antenna. The field of a short vertical antenna on a homogeneous ground was shown to be modified by the presence of a metallic screen in the form of a circular disk and a concentric sector. The modification of the field was expressed in the form of surface integrals over the disk and the sector. Extensive numerical results were obtained for these basic integrals.

The Theory of an Antenna Over an Inhomogeneous Ground Plane. An antenna over a flat ground plane, characterized by a variable surface impedance, was considered theoretically. The problem was formulated in terms of the mutual impedance between two vertical dipoles. The ground screen was taken to be in the combined form of a circular disk and a concentric sector. An approximate solution of the problem was obtained and the results were compared with previous investigations of closely related work.

Curves for Ground-wave Propagation Over Mixed Land and Sea Paths. Specific numerical results were obtained for ground-wave propagation over paths part of which are over sea and part over land. The problem is idealized to the extent that the earth is a smooth, spherical surface. The method is based on a previous formulation in terms of mutual impedance between two vertical electric dipoles of an inhomogeneous spherical earth. Amplitude and phase of the ground wave were given for various combinations of the following parameters: frequency 1000, 100, and 20 kc/s; land conductivities 100 and 10 mmhos/meter; and a sea conductivity of 4 mhos/meter. Most of the curves exhibit the well-known recovery effect which occurs beyond the coastline for propagation from land towards the sea.

Wave Propagation Around a Curved Boundary Containing an Obstacle. The field of an electric dipole on a smooth spherical or cylindrical surface containing a localized obstruction was calculated. An approximate solution was obtained by combining the rigorous theory of diffraction by a sphere and the approximate Kirchhoff diffraction theory for black screens. The application to ground-wave propagation over mountains was demonstrated.

Oblique Propagation of Radio Waves Across a Coastline. The theory of mixed-path groundwave propagation was extended to cover oblique incidence at a straight coastline. To allow for a varying water depth, the surface impedance was allowed to change gradually from sea to land. The resulting two-dimensional integral equation was solved by a perturbation method and the solutions for an abrupt coastline and other idealized situations were obtained as special cases. The apparent field singularities which emerged in the limiting cases were shown to have a real physical significance. Using an approximate boundary condition, the influence of a gradual elevation change at the coastline was considered also.

Guided Electromagnetic Waves in the Earth's Crust. A natural waveguide for electromagnetic waves may exist in the earth's crust. The attenuation in such a guide was calculated for an idealized model under more or less optimum conditions. The results obtained by choosing certain dimensionless parameters may have rather broad applications to problems of this type.

Electromagnetic Scattering From a Sphere. The generalization of the Lorenz-Mie theory for scattering from a homogeneous sphere to a radially inhomogeneous sphere was carried out. In this case the scatterer consists of a spherical body with any number of homogeneous or inhomogeneous concentric regions. The treatment makes use of the analogy with nonuniform transmission line theory. The results have application to radar techniques for investigating ionized clouds.

VLF Radio Propagation in an Anisotropic Ionosphere. The theory of the propagation of electromagnetic waves in the space between a spherical conducting earth and a concentric ionospheric reflecting layer was treated a novel manner. The problem was idealized to the extent that the tangential field components at the boundaries of this spherical waveguide are related in a prescribed way. At the ground, the relation involves a scalar surface impedance, while it was found necessary to employ a reflection coefficient or surface impedance for the ionosphere in the form of a matrix. A solution was sought for the total field produced by a vertical electric dipole and explicit results were obtained by assuming azimuthal symmetry. A representation in terms of guided waves was obtained by applying the Watson transformation and used to obtain specific results.

Excitation of Modes at Very Low Frequency. The concept of VLF radio waves being propagated between the earth and the ionosphere in the manner of a waveguide has proved very useful. As much neglected aspect of the subject, however, is the manner in which the modes of propagation are excited. A valid analysis requires that the earth's curvature and the grazing nature of the modes be properly accounted for. An expression for the excitation factor was obtained by using Airy integral or third-order approximations for the spherical wave functions. It was indicated that the modes of very low attenuation may be accompanied by excitation factors much less than unity. There is evidence of this phenomenon in some old experimental data at frequencies of the order of 25 kc/s. A mode of this type can be imagined as becoming "detached" from the lower boundary of the earth-ionosphere waveguide. In this situation, the height-gain functions increase with height and the modal characteristics depend only slightly on ground characteristics.

Height Gain for VLF Radio Waves. The height dependence of the field strength of VLF radio waves was considered. Using previously developed theory, the height-gain function of the first two modes was calculated in terms of Airy functions of complex argument. For frequencies of the order of 25 kc/s, the height-gain function reaches a maximum value at a height of about 40 km, for a reflecting layer at about 70 km. The form of

the height-gain function was also shown to be dependent on the finite conductivity of the ground. An experimental curve, for 18.0 kc/s, based on a rocket measurement shows some agreement with the theory.

Characteristics of an Inhomogeneous D-layer at VLF. The vertically polarized reflection coefficient from a horizontally graded *D*-layer was calculated, using wave methods. The exponential conductivity profile was given special attention, as being representative of the daytime quiescent ionosphere. The results showed that the gradient of the lower ionosphere is most important in determining the magnitude of the reflection coefficient at highly oblique incidence. However, the functional relationship between the gradient and the reflection characteristics is not simple; a sharp gradient, for example, is not always associated with high reflection coefficients at VLF, contrary to repeated statements in the literature. The results were also extended to a study of the relation between attenuation and phase velocity of the waveguide modes when the ionosphere is not sharply bounded.

The influence of idealized perturbations on the undisturbed profiles was also considered. The results demonstrated, among other things, what levels in the lower ionosphere are most effective in VLF propagation. While the general results were complicated, some important basic principles concerning the reflection coefficient were established.

Propagation in a Nonuniform Earth-Ionosphere Waveguide. An approximate theory for propagation of electromagnetic waves in a curved waveguide of variable width was developed at the Bureau, based on a direct application of the Lorentz reciprocity theorem. The final result is in the form of a line integral which involves the profile of the ionospheric reflecting layer as a function of the horizontal distance. By making a number of simplifications, valid for small perturbations, the physical consequences of nonuniform reflecting height were made evident. It was indicated in particular that perturbations at the reflecting level introduce higher-order modes in the waveguide. The results have application to the theory of VLF radio wave propagation when the ionospheric heights are not constant along the path.

Microwave Models for VLF Propagation. Work has continued on the study of microwave models of VLF radio propagation, in collaboration with the University of Colorado. The rectangular waveguide used as a model has approximately the same width in wavelengths, measured at 9Gc/s, as the height of the ionosphere, at 15 kc/s. The waveguide has a modal equation approximately the same as that of the earth-ionosphere waveguide at VLF frequencies. Perturbations in the walls of the waveguide affect propagation through it in a manner similar to that in which ionospheric perturbations affect propagation through the earth-ionosphere waveguide.

Experimental studies were made of propagation in the waveguide with several different wall perturbations. It was found that wall perturbation causes the conversion of substantial amounts of energy from one of the propagating modes to others, as suggested by theory. Since there are 15 propagation modes in the waveguide, the effects of the perturbation are

noticeable at great distances from it. Furthermore, it was found that the amount of energy converted to various propagating modes is critically dependent upon the size and shape of the perturbation. Because of this fact, it should be possible to determine the approximate size and shape of ionospheric perturbations from field measurements at the surface of the earth.

Theory of Magnetotelluric Fields. A general theory of magnetotelluric fields was developed in connection with the combined analyses of the geomagnetic and the telluric (earth current) fields on the surface of the earth. The usual objective of such investigations is to obtain information about the earth's crustal layers, but in this case it is desired to understand something about the source of the fields. Possible source mechanisms were reviewed and detailed study of previous work on the theory of magnetotelluric interpretation was carried out. A number of three-layer interpretation curves were prepared, which also can be applied to radio propagation over a stratified conductor.

2.3.5. CRYOGENIC ENGINEERING

The cryogenic engineering activities, centered at the Boulder Laboratories, provide information needed for practical applications of materials, systems, and techniques at very low temperatures. Missiles and space programs relying on cryogenic liquids as propellants, and scientific programs requiring extremely low temperatures, have increased the demand for information from the cryogenic engineering laboratories. To cooperate in these activities, the Bureau conducts research to determine the physical properties of materials at cryogenic temperatures and develops methods for measuring these properties and the characteristics of cryogenic systems. In addition, it maintains a national Cryogenic Data Center where information on cryogenic engineering is collected and organized for use by other Government agencies, industry, and the public.

Dielectric Behavior of Dense Parahydrogen. Urgent demands by design engineers for data on parahydrogen have resulted in extensive measurements by the Bureau with support from the National Aeronautics and Space Administration (NASA). Such investigations involve studies of the dielectric constant of parahydrogen.

The dielectric constant of a nondipolar fluid may be represented as a function of density with good accuracy by the classical formula of Clausius-Mossotti. However, deviations in dielectric constant, caused by the effects of transient dipoles, permanent multipole moments if present, and changes in the molecular polarizability due to interactions with close neighbors, may occur.

The theories of such effects have developed rapidly in the past decade but are not yet quantitatively accurate. Also, experimental data accurate enough to clearly show these small effects are scarce. Hydrogen is not a particularly good substance in which to study them, since neither its reduced polarizability nor its electric quadrople moment is very large. However, the avail-

ability of accurate density data recently determined by the Bureau offsets this disadvantage. Knowing the dielectric constant accurately is important to scientists and engineers because many instrumental techniques for determining density, liquid level, and quality of a fluid depend on capacitance measurements.

Polarization isotherms for hydrogen have been determined from 20 to 90 °K at pressures up to 30 atm covering both the liquid and gaseous states. These isotherms rise with increasing density to a maximum, and then fall. This behavior is in qualitative accord with the prediction of theory and the limited experimental data on related substances. These are the first data on hydrogen of sufficient precision to show departures from Clausius-Mossotti behavior.

Superconductivity. The Bureau, in conjunction with the Atomic Energy Commission (AEC), is investigating the energy gap in superconducting thin films as a function of film thickness, temperature, and magnetic field. Critical fields of tin and lead films have been determined by measuring the magnetic field at which the energy gap vanishes. Analysis of the data in

Cryostat and magnet used in investigating superconductivity in thin films. **(See p. 180.)**

terms of the Bardeen, Cooper, Schrieffer (BCS) theory of superconductivity is aided by computer techniques. Magnetization measurements on cold drawn niobium wire can best be interpreted in terms of the Ginzburg-Landau, Abrikosov, Gor'kov (GLAG) theory of superconductivity. Mathematical research extending this theory affords better interpretation of the results.

Magnetic Properties in Silicon Steel. Bureau scientists are employing a magneto-optic apparatus to observe the domain structure in silicon steels as small stresses or changes in temperature occur. Unlike the powder pattern technique, this apparatus reveals the complete surface domain structure without regard to the type of domain wall. The behavior under stress of a new pattern, termed the "chevron," has been noted.

Low-Temperature Seals. A program concerned with improving low-temperature seals is being carried out by the Bureau in cooperation with the U.S. Air Force. In these studies the thermal expansion properties and brittle transition temperatures of about 40 elastomers, representing eight basic polymer types, were measured. These results, combined with resilience and differential thermal analysis measurements, are being used to predict the usefulness of these materials as low-temperature seals.

Cryogenic Literature Service. The Cryogenic Data Center's documentation unit searches the world literature for technical information pertinent to the cryogenic engineering field and promotes an awareness of such literature to the Bureau staff and the cryogenic industry. Some 4100 new references were coded and entered into the Center's storage and retrieval system. Special attention was still given to low-temperature data on the "properties of fluids" and "properties of solids" categories; thus 1500 of the new entries were in these categories. The versatility of the computer search program was increased when the program was converted to suit a new computer. A number of extensive bibliographies on properties of materials was compiled during the year.

More than 2500 documents were procured from world sources for the Bureau staff. About 600 of these were in microform, which is less costly and often of better quality than full size copy. The staff distributed an estimated 20,000 items of NBS literature in response to some 1500 requests. Announcements of available material and services are sent, at three-month intervals, to approximately 4000 persons and institutions on the Center's mailing list. Arrangements are also being made to provide the NBS material in microform, thus greatly reducing reproduction cost and facilitating handling. Use of technical literature in this form is becoming more popular now that good readers and printers are available at reasonable prices.

The documentation unit works closely with the Center's evaluation unit in providing literature-procurement services and in bibliography retrieval. The evaluation unit is not only a primary user of these services, but is also a major contributor of information on cryogenic literature from their compilation programs and the associated literature searching on selected topics.

Thermophysical Properties of Cryogenic Materials. With support from NASA, the Cryogenic Data Center is evaluating and compiling data on the thermophysical properties of materials from the scientific literature. The objective is to publish authoritative and comprehensive tables and graphs of data in a form convenient to scientists and engineers studying cryogenic phenomena and designing cryogenic systems. If the desired data to complete a table are not available from the literature, values are computed from correlations based on theory and the properties of related materials.

Considerable progress has been made in compiling thermodynamic data on the properties of neon and carbon monoxide. The resulting tables, together with property charts and a description of computational methods, will be published by the Bureau. A temperature-entropy diagram for nitrogen has also been constructed and is now available. Interim reports with preliminary tables for oxygen and argon are being prepared for use while further evaluations of these elements are in progress. Collections of data on the surface tension values and dielectric constants of cryogenic fluids and the electrical resistivity values for pure metals are also being evaluated.

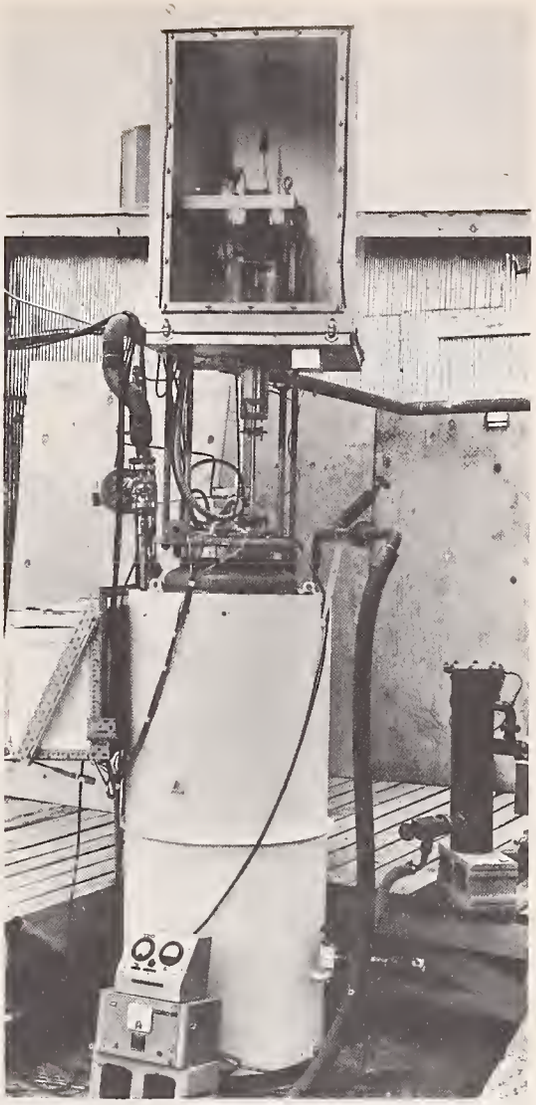
In other work, extensive bibliographies on the thermophysical properties of fluorine and on the thermal conductivity of cryogenic liquids were completed during the year. Bibliographies on the properties of argon and on the saturation properties (i.e., vapor pressure, saturation densities, latent heats, specific heats at constant saturation) of the cryogenic fluids are nearly complete.

The thermodynamic properties of cryogenic fluids at low pressures have been computed at the Georgia Institute of Technology under an NBS contract, as a part of this compilation program. During the past year reports on this activity, which include extensive tabulations of data, have been issued on the vapor pressure and heats of vaporization and sublimation of methane, nitrogen, and fluorine.

Fluid Flow and Heat Transfer Phenomena. Information on fluid flow and heat transfer phenomena are necessary to provide design information in cryogenic systems. One specific problem occurs in cryogenic liquid-vapor flow where the mass rate of flow is often limited by choking in a restriction such as a valve or at the exit of a system. This choking two-phase flow differs from similar single phase problems and often the choking flow velocity is reduced by an order of magnitude or more. Idealized solutions for predicting the upper and lower limits of choking two-phase flow for cryogenic fluids have been completed. These solutions are intended for use as design guides and as computational aids for research projects.

The characteristics of a number of pieces of equipment, particularly pumps, are markedly changed if vapor is formed in a flowing cryogenic liquid. Studies have been underway to determine the nucleation or bubble-forming characteristics of cryogenic liquids. These studies show that in static systems the pressure may be reduced below the vapor pressure before the vapor phase occurs.

Equipment exposed to the atmosphere (such as vaporizers, uninsulated



Liquid hydrogen cryostat for testing fluid level sensors. Tests are made of such characteristics as repeatability and response time. **(See p. 183.)**

cryogenic fluid transfer lines, air dryers, and missile tanks) has very low-temperature surfaces. A study concerned with the characteristics of frost formation and heat and mass transfer on such surfaces is nearing completion.

Studies of fluid flow and heat transfer processes occurring during the cooldown of cryogenic transfer lines are underway. Experimental data for liquid nitrogen flow in an insulated, transfer line have been obtained. Cooldown times vary with initial flow conditions, and maximum surge pressures measured in the system were found to be up to three times the initial driving pressures. Analytical work to provide design data for the cooldown process is in progress.

Cryogenic Instrumentation. A study of cryogenic instrumentation is being conducted with support from NASA. Transducers for accurate, precise measurements of the liquid level, temperature, and mass flow of cryogenic fluids are being investigated. Both theoretical and experimental research are being conducted to define and extend the use of the predominate intensive coefficients for measurements.

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A state-of-the-art evaluation of commercial liquid-level point sensors for hydrogen involving 18 manufacturers has been completed. Some of the devices tested indicated liquid hydrogen level repeatability within 0.020 in. Response times on some types were approximately 5 and 10 msec, respectively, as the devices were immersed and withdrawn from liquid hydrogen. Types of devices tested included resistive, capacitive, optical, piezoelectric, magnetostrictive, and vibratory (low-frequency paddle).

Cryopropellant Research. A study of the bulk density of boiling liquid oxygen, stimulated by the needs of rocket propulsion programs, has been completed by the Bureau with support from NASA. Satisfactory agreement was obtained between the theoretical analysis and the experimental research to determine the mass and volume of propellant aboard a vehicle at

Investigation of cryopropellant freezing phenomena. Propellants leaking or venting in low-pressure environments may cause solids to form in critical regions, resulting in possible failure of space vehicle propellant systems. **(See p. 184.)**

any time. The theoretical analysis was also applied to boiling liquid hydrogen. Analytical results demonstrate the ratio of bulk density to saturated liquid density to be a function of a parameter involving saturated liquid properties and tank geometry. For liquid oxygen, the change in bulk density is not large—approaching a maximum value of three percent at the extreme conditions of large heat input rates, tall liquid columns, and small diameters. For low-density, low latent heat (per unit volume) liquid such as liquid hydrogen, the predicted change in bulk density is much greater.

In other work, problems in utilizing cryogenic propellants at high altitudes are being investigated. One such problem is associated with the formation of solids in critical areas. These formations can obstruct or retard flow and thereby cause a malfunction in the propellant system of a space vehicle. Also of interest is the effect of micrometeorite punctures in the propellant storage system. Either a free or obstructed flow of propellant to the ambient low-pressure region in such cases would result, depending upon the solid formation (plugging) characteristics of the situation. Both qualitative and quantitative studies are now in progress on those variables which may influence the solid formation in cryopropellants—particularly in liquid hydrogen and liquid oxygen. Experimental information obtained thus far indicates that cryopropellant flow may be closely predicted by conventional adiabatic incompressible fluid flow equations utilizing empirical (handbook) orifice-flow coefficient data.

Refrigeration Processes. The development of methods for providing refrigeration in the cryogenic temperature range is important to military, industrial, and research programs. Computational work, aided by a digital computer, is being performed on classical refrigeration processes. Correlations, resulting from the study, will make it possible to design composite refrigeration systems with increased operating efficiency. With the partial support of the Atomic Energy Commission, the Bureau is conducting a theoretical study of feasible cycles adaptable to the temperature region 1.5 to 30 °K.

Expansion engines are vital components of refrigeration systems. The development of a miniature high-speed turbine expander supported by hydrostatic (externally pressurized), helium gas-lubricated bearings is continuing. An improved design of expander nozzles and rotors has given a 0.3116-in.-diam turbine rotor speeds of 11,000 revolutions per second at an adiabatic efficiency of 80 percent when operating with a pressure ratio of 4:1.

Consultation and Advisory Services. The Bureau provides cryogenic engineering consultation and advisory services in several areas. Other Government agencies utilize the broad experience of NBS personnel in designing equipment and handling cryogenic fluids. For example, the Bureau is providing consultation and advisory services to the Air Force Cambridge Research Laboratory in connection with cryogenic problems encountered in developing a cryogenic "whole air" sampler. The sampler, carried by rockets into the upper atmosphere, uses liquid hydrogen to condense the air

sample as it is being collected. This means for sampling the atmosphere promises to be much more effective than equipment currently in use.

Assistance is being given to Projects Centaur, Rover, and NERVA under the sponsorship of National Aeronautics and Space Administration. The Centaur, first space vehicle to use liquid hydrogen as a propellant, will be followed by the nuclear rocket programs, Rover and NERVA, that are planning more extensive use of liquid hydrogen. The physical properties of hydrogen are sufficiently different from other propellants to present many new problems to the industry. Principal contractors of these programs receive Bureau support in the areas of ground support equipment, insulation, instrumentation, thermodynamics, and plans, specifications, and equipment review.

In cooperation with the Central European Organization for Nuclear Research (CERN), Geneva, Switzerland, NBS personnel tested and evaluated a hydrogen liquefier at the Bureau facilities.

Under the sponsorship of the Atomic Energy Commission, the Bureau assisted in evaluating air dielectric coaxial cables as cryogenic transfer lines. Such high-frequency electrical transmission cables having suitable physical configuration were found to be useful for transferring certain cryogenic fluids and could substantially reduce initial investments for transferring these fluids.

Liquefied and Purified Gases. All of the liquefied gases used at the Boulder Laboratories are now procured from commercial sources; none has had to be produced with the NBS facilities for more than a year. The helium liquefier is still being maintained in a ready standby condition, however, because of some uncertainties in commercial transportation delivery. The liquid hydrogen plant is still being used to repurify hydrogen gas collected from liquid evaporation and for research and development on cryogenic systems. The liquid nitrogen plants have been listed as surplus and are available for transfer to another agency.

The approximate amounts of liquefied gas procured this year were as follows: 830 liters of helium; 50,000 liters of hydrogen; and 370,000 liters of nitrogen. Most of these liquids were distributed to laboratory projects; however, small amounts of liquefied and pure gases were distributed to some 12 laboratories outside the Bureau which had no other convenient source of supply. More than 100,000 scf of hydrogen gas were collected and repurified for laboratory use; no hydrogen gas was purchased for this purpose. About 60,000 scf of nitrogen gas were used during the year, essentially all of which was provided by the vaporization of liquid nitrogen.

2.3.6. BUILDING RESEARCH

The Bureau conducts research in chemistry, physics, and engineering to obtain data on the properties and performance of building materials, structures, and equipment; and develops methods for testing materials, mechanisms, and structures. The Bureau assists other laboratories engaged in building research by devising techniques for accurate measurements, develop-

ing and supplying calibrated laboratory reference standards, and participating in interlaboratory programs for checking measurement precision. Cooperation with public and private agencies to develop and improve code and standards for safe and effective use of materials and equipment is also an important part of the overall program.

A consultant service is maintained to advise Government agencies on building problems, and to aid public and private organizations in formulating specifications and national standards that concern the building industry. For example, the U.S. Air Force Academy consulted the Bureau before choosing sealants suitable for the joints between aluminum-faced roof elements of the Academy Chapel; and the National Gallery of Art called upon the Bureau to help select a sealant for glass skylights.

Explosions on marine tankers after shipments of fuels and chemicals have prompted the Secretary of the Treasury to appoint a "Special Committee on Tanker Hazards." An NBS staff member serves on this committee which is studying the hazards of vapors associated with the cargoes in the ullage and other spaces in such vessels.

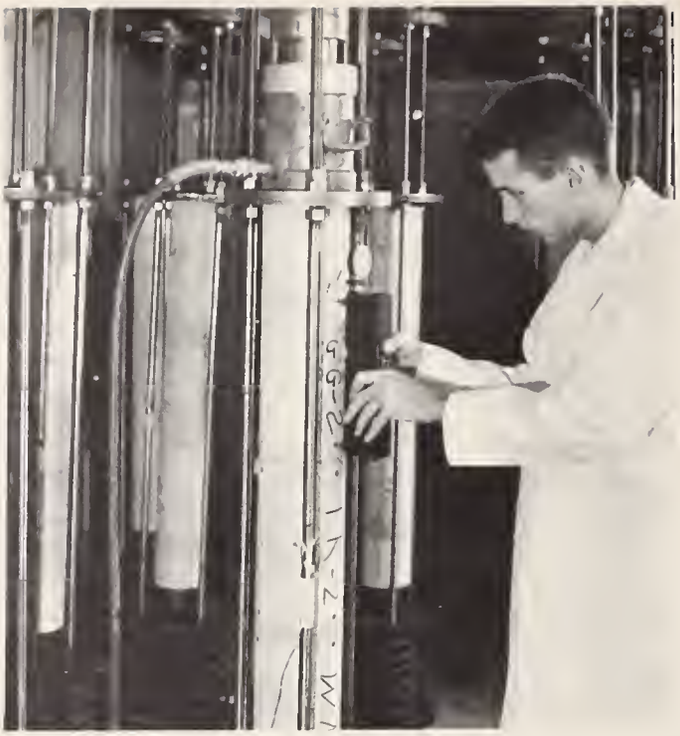
During the year, members of the staff conducted a symposium on Fire Test Methods for the Committee on Fire Research of the National Academy of Sciences—National Research Council. Another Symposium on Measurement of Thermal Radiation Properties of Solids was sponsored jointly by the Bureau, the Air Force, and the National Aeronautics and Space Administration.

Building Codes and Safety Standards. In performing its responsibility as the sole sponsor, the Bureau reorganized the Committee on Building Code Requirements for Masonry of the American Standards Association (ASA) and added 12 new members. The Committee began revising the American Standard Building Code Requirements for Masonry about midyear when a subcommittee prepared and reviewed a first draft, based upon responses to a widely circulated request for suggestions.

The Bureau, as sole sponsor, reactivated and increased the membership of ASA's committee on Building Code Requirements for Minimum Design Loads in Buildings. The seven organizations and nine general-interest members added to this Committee are all exceptionally well qualified to contribute to the Committee's work.

Through membership on committees operating under procedures of the ASA, the Bureau assisted in (1) revising the National Electrical Code, (2) developing plumbing, heating, and electrical standards for mobile homes and travel trailers, (3) preparing a proposed revision to the National Plumbing Code, (4) reviewing existing standards for plumbing materials, (5) preparing a proposed revision to the Safety Code for Elevators, and (6) preparing proposed safety codes for mechanized parking garage equipment, cranes, derricks, and hoists; and powered platforms.

Creep and Shrinkage of Structural Lightweight Concretes. During the past three years, the Bureau, in cooperation with the Expanded Shale, Clay, and Slate Institute, has conducted experiments on the creep and



Measurement of creep in cylinders of lightweight concrete subjected to a constant stress of 2000 psi. Creep is important because it affects the long-term deflections in reinforced concrete structures. (See p. 187.)

shrinkage of lightweight aggregate concretes and has compared the results with concretes containing normal weight aggregates.

Although creep values among individual aggregates varied a great deal, the magnitude of creep for a concrete made with a given aggregate was found to vary approximately linearly with the ratio of applied stress to the strength of concrete at the time of initial loading. The investigation indicated that both creep and drying shrinkage values were slightly higher for lightweight concrete and that the 2-year creep of a concrete can be estimated with an acceptable accuracy from observations made after 90 days of loading.

Joint Sealants for Building Components. With the support of the Army, Navy, and Air Force, the Bureau maintains a joint sealant laboratory where scientific test data on the properties and performance of sealant formulations are obtained. These data form the basis of standard test procedures which are incorporated in both Federal and American Society for Testing and Materials (ASTM) Specifications. Both specifications serve as guides for architects, builders, and engineers in selecting suitable sealants. Draft specifications for the one-component, chemically curing type (polysulfide, silicone, urethane, etc.) and the one-component, volatile curing type (butyl, chloro-sulfonated polyethylene, acrylic, etc.) are being prepared. Also, as a result of recent research and field experience, revisions are being made in the specifications for two-component rubber base sealants and one-part oil and resin base types.

Waterproofing Underground Structures. The Army, Navy, and Air Force support a Bureau program in which materials potentially useful for waterproofing underground structures are investigated. The immediate

need for such information is related to missile sites, but such knowledge will be applicable to other underground structures, including basements of houses, and, in part, to roofs.

A device, built to simulate the damage that could occur from a backfilling operation and from high water pressure, was employed to test a number of materials. The test results were compared with various physical tests performed on the material such as tensile strength, bursting strength, puncture resistance, and tear strength. Although there was considerable agreement in the results, there were exceptions to any single test or combination of tests. The laboratory work indicates that the large number of plies usually specified for waterproofing deep underground structures can be reduced.

Colloidal Nature of Asphalts. Recent experimental work at the Bureau shows that the asphaltene fraction (the dispersed phase) of asphalt carries a charge, as proposed in the colloidal theory of asphalt.

In this work the asphaltenes were separated from the asphalt, suspended in nitromethane, and introduced into a microelectrophoresis cell. Aided by a microscope and a calibrated grid, the rate of movement of the particle at a selected potential was determined. The electrophoretic mobility of the asphaltenes was then calculated.

Attempts to correlate electrophoretic mobility with the weathering durability of six asphalts, as determined by other means, were unsuccessful. The charge on the asphaltenes and, consequently, polar bonding forces probably play a minor role in asphalt durability.

Photo-oxidation Products in Plastics Identified. A sensitive colorimetric method for measuring photo-oxidation in fiberglass-reinforced polyester plastics was applied, with modifications, to poly(vinyl chloride), poly(methyl methacrylate), and cellulose acetate-butyrate plastics systems. Weathered specimens, when treated with simple phenylenediamines, develop a pronounced color. Spectroscopic analysis of acetic acid solutions of exposed poly(methyl methacrylate-diamine) and cellulose acetate-butyrate-diamine reaction products showed distinct absorbance peaks in the ultraviolet and visible regions, respectively. Similarly, certain pure organic compounds were found to react with diamines to produce colored products with absorbance peaks in the visible and ultraviolet regions. Photo-oxidation products could then be identified by matching the absorbance peaks.

Fluid Dynamics of Plumbing. The writers of plumbing codes and equipment standards, as well as design engineers, lack specific information on the complex fluid dynamics of plumbing needed to determine safe, economic pipe sizes, configurations, and designs.

A current study, sponsored by the National Association of Home Builders, indicates the possibility for reducing costs and increasing the flexibility of plumbing fixture arrangements by designs which minimize the need for vent piping.

Test Methods for Air-Conditioning Units. Laboratory data on the cooling capacity of air-conditioning units by three different test methods were used for analyzing the probable measurement errors in several test

procedures. The three kinds of capacity measurements agreed within 4 percent in a large majority of the tests. The investigation indicated the need for better wet-bulb and refrigerant flowmeter instrumentation as well as for more data on air mixing techniques and heat-of-mixing of various refrigerants and oil.

Test Methods for Refrigerated Trucks. Laboratory investigations leading to the development of a testing and rating method for refrigerated trucks were carried out under the joint sponsorship of the U.S. Department of Agriculture, the Truck-Body and Equipment Association, and the Bureau. An apparatus for simulating the effect of solar radiation on the cooling load of stationary refrigerated trucks was designed and constructed. Prototype vehicles of several designs, used to study the effect of solar radiation, and of air, moisture, and heat transmission through the body, showed that air and moisture transmission differs significantly for different constructions. Such studies also show that the effect of solar radiation can be satisfactorily accounted for by a correction factor applied to the steady-state heat transfer calculation.

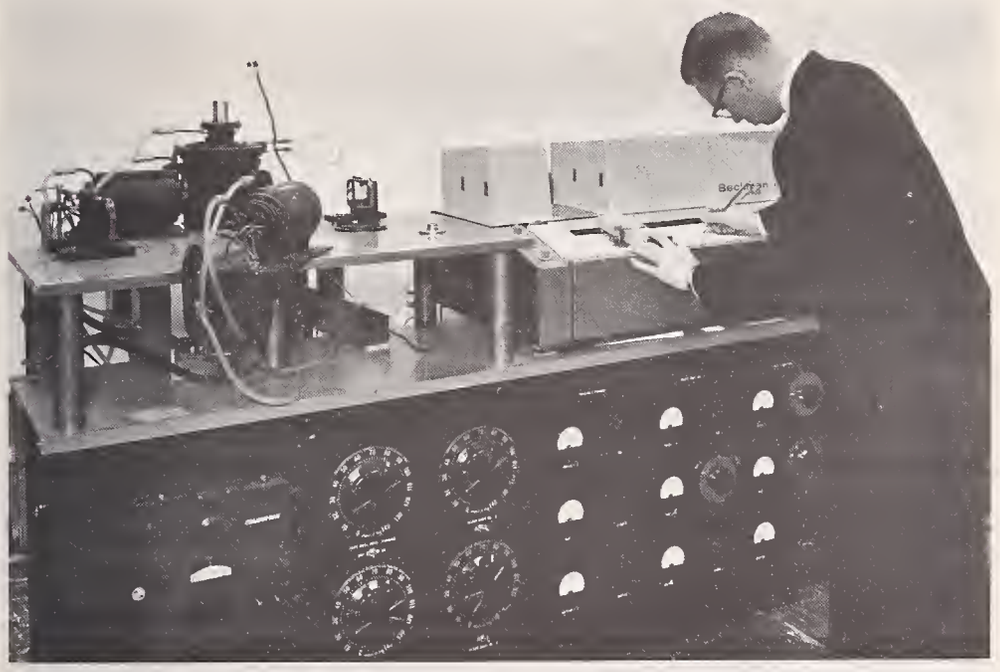
Criteria for Heating and Air-Conditioning Ducts. Upon completion of a study sponsored by the Federal Housing Administration, the Bureau recommended test procedures for evaluating the resistance of heating and air-conditioning ducts to mold growth, odor emission, deformation at high humidity and high temperature, bending and crushing deformation, impact resistance, erosion, airtightness, and resistance to rupture or collapse from internal pressure. The investigation also provided information on the characteristics of selected ducts made of cement asbestos, glass fiber, paper laminate, and metal. Flame-spread characteristics of ducts are being investigated separately at another laboratory.

Thermal Emittance of Ceramic Oxides. As a class, the ceramic oxides have high melting temperatures and good chemical stability when heated in air. These properties make them useful for such applications as furnace linings, fire barriers, re-entry nose cones, and as construction materials for inboard power supplies in space vehicles. However, for these materials to be used with maximum advantage, their high-temperature thermophysical properties must be known; one of the more important of these properties is the thermal emissivity.

Recently, at the request of the National Aeronautics and Space Administration (NASA), the Bureau designed and constructed equipment for measuring normal spectral emittance of ceramic oxides in the 1 to 15 micron (μ) range and at temperatures up to 1800 °K. In this equipment, specimens in the form of hollow cylinders are rotated in a furnace cavity to reduce the temperature gradient existing between the inside and the outside of the specimen. The ratio of the energy emitted by the specimen to that emitted by a blackbody furnace at the same temperature is a measure of the thermal emittance, and is automatically recorded by a double-beam spectrometer over the range of 1 to 15 μ.

Automation of Thermal Emittance Measurements. A data-recording and processing attachment has been built and installed on a double-beam, ratio-recording spectrometer. The device automatically records corrected spectral emittance data on punched paper tape. Data from the tape can be entered directly into an electronic digital computer for computation of total emittance or the integrated absorptance for radiation of known spectral distribution. The attachment can also be used to compute any of these properties during a determination of spectral emittance by the selected ordinate method. This device was developed in a program sponsored by the Air Force.

Thermal Conductivity Reference Materials. Thermal conductivity reference samples are needed by industry and other laboratories to confirm or compare thermal conductivity measurements, or to calibrate comparative methods of conductivity measurement. Extensive measurements to explore the stability of a chromium-nickel alloy, and the degree to which it may be affected by its thermal history, have been made using electrical resistance measurements. Thermal conductivity results made by a cooperating laboratory over the temperature range 200 to 1100 °C on a sample of this alloy agree with Bureau results within two percent. Sixteen samples of this alloy have now been made available to other laboratories, on a preliminary basis. Preliminary work has begun on a cerammed microcrystalline glass in a program to develop a much needed reference material of moderate thermal conductivity. This work was supported in part by the Navy.



Measurement of the spectral emittance of a ceramic oxide specimen at 1400 °K. Because the ceramic oxides have high melting temperature and good chemical stability, they are useful in furnace linings, fire barriers, rocket nose cones, and inboard power supplies in space vehicles. For these applications, however, the high-temperature thermophysical properties, such as thermal emissivity, of these materials must be carefully charted. **(See p. 190.)**

Thermal Conductivity Measurements by Radial Heat Flow. In connection with thermal conductivity measurements on powder insulations at high temperatures, the Bureau made a mathematical analysis of line heat source arrangements for a radial heat flow system. The study showed that that the positions of the axial heater and inner radius thermocouples of a radial-flow system could be interchanged, with material experimental advantages in some cases. For example, one thermocouple can serve in place of several, and can be protected against contamination, or be renewed readily, without disturbing a measurement.

Performance Specification for Insulated Flat-Roof Constructions. A draft of a performance specification for insulated flat-roof construction subjected to moisture has been prepared for the Army, Navy, and Air Force, the sponsors of the investigation. The specification gives performance requirements for insulated roof constructions. for ordinary occupancy and climates, that are capable, if wetted, of self-drying under seasonal in-service conditions as a result of solar heating of the roof. The studies showed that after the leak is patched, an insulated flat roof, if it is self-drying, will recover most of its insulating value, without replacing the insulation or the roofing.

Heat of Hydration of Portland Cement. As portland cement hydrates, a substantial amount of heat is released. To prevent damage to massive structures, such as large dams, by the accumulation and subsequent release of the heat generated within the structure, designers must know the heat of hydration of various cements. Calorimeters for determining these data are calibrated with reagent-quality zinc oxide. Heat-of-solution values currently used for zinc oxide were determined in 1933.

One of three sets of equipment used to check cement and concrete testing apparatus by the NBS Cement and Concrete Reference Laboratory in a joint U.S. Government—ASTM program. The service is available throughout the United States and Canada.

Recently, using a precision calorimeter, the Bureau determined the heat of solution of 12 lots of reagent-quality zinc oxide obtained from different manufacturers in the United States, Great Britain, Germany, and Japan. Results showed an average value only slightly higher than the currently accepted value. Further, no significant differences in heat of solution were found among the 12 lots. Consequently, measurements made with different cement calorimeters, wherever calibrated, should not differ from each other due to differences in the source of the standardizing substance.

Electron Capture of Combustion Inhibitors. Certain gaseous flame-inhibiting agents show high electron attachment coefficients. Results of electron attachment studies on 23 halogenated hydrocarbons show that they exhibit electron attachment coefficients significantly higher than that of oxygen. There appeared, with some exceptions, to be qualitative correlation between electron attachment and flame extinguishment effectiveness of the inhibitors. However, the significance of this finding is not clear, considering that there are compounds exhibiting high electron attachment coefficients which cannot be considered useful as flame inhibitors.

Surface Flame Propagation. The radiant-panel flame-spread test method, previously developed by the Bureau, has been adopted as an Interim Federal Standard and as a tentative test method for research and development purposes by the ASTM. Performance of this test results in a flame-spread index composed of two factors, representing the ignition sensitivity and the maximum rate of heat generation by the material. Recently completed studies on selected cellulose-type materials have delineated some important physical and thermal properties which influence surface flame propagation on simple and composite slabs. Results of these studies indicate that flame propagation in these materials consists of progressive ignition of the solid when a characteristic temperature is reached.

Fire Research Contracts. The Bureau, in cooperation with the Office of Naval Research, the Office of Civil Defense, the Advanced Research Projects Agency, and the National Science Foundation, is supporting fundamental work in the field of self-ignition phenomena and the mechanism of fire extinguishment. Two aspects of this work have been completed by publication of the findings. The first of these consisted of a study of combustion phenomena by means of mathematical techniques. The refinements introduced in this study for predicting performance of self-heating materials, show that the finite difference method developed provides a significant improvement over other mathematical techniques previously available.

In the second part of the study, the field of fire extinguishment, research for the purpose of clarifying the mechanism by which chemical powders are effective in terminating combustion reactions, has been studied. It was found that the introduction of 6 percent potassium vapor into a methane diffusion flame had no inhibition effect, but bromine compounds introduced at the same concentration proved to be very effective inhibitors.

2.3.7. WEIGHTS AND MEASURES

The control over commercial weighing and measuring in the United States is principally the responsibility of the political subdivisions of the Federal government—the States, counties, and cities. Such local control allows problem solutions to be patterned to local conditions. However, to avoid the possibility of 50 different weights and measures systems, the U.S. Department of Commerce—and through it, the National Bureau of Standards—has been charged by the Congress with the custody, maintenance, and development of the national standards of measurement, and with the provision of means and methods for making measurements consistent with those standards. To assist the State weights and measures programs, the Bureau tests and calibrates State standards and standard measuring apparatus and provides technical advisory services. To assure uniformity in weights and measures laws and in methods of inspection, the Bureau extends general cooperation to State weights and measures officials.

To carry out this program, the Bureau maintains an Office of Weights and Measures which is responsible for (1) technical assistance to the States and to business and industry in the area of measurement; (2) the design, construction, and use of weights and measures standards and of instruments associated with such standards; (3) the training of weights and measures officials in the technical aspects of their programs; and (4) the collection, arrangement, and dissemination of technical data on measurement units and systems.

Technical Assistance Program. With increases in personnel, the Office of Weights and Measures has expanded its technical services, and assistance is now being given on a continuing basis in the design of State laboratory facilities. During the year, plans for such facilities have been provided to the States of New Mexico, Pennsylvania, Tennessee, and Wisconsin.

Package-checking techniques for products that are difficult to check—for example, aerosol containers and frozen food packages—were outlined and demonstrated. For such products, dependable quantity determination methods have not previously been available in convenient form for weights and measures officials.

A preliminary investigation was made of pipe meter provers, with more detailed studies planned. In an investigation undertaken because of the recent use of small flowmeters in the marketing of fuel oil, a system was developed for the testing of so-called "slow-flow" meters. An extensive investigation of the accuracy of rental-car odometers was completed.

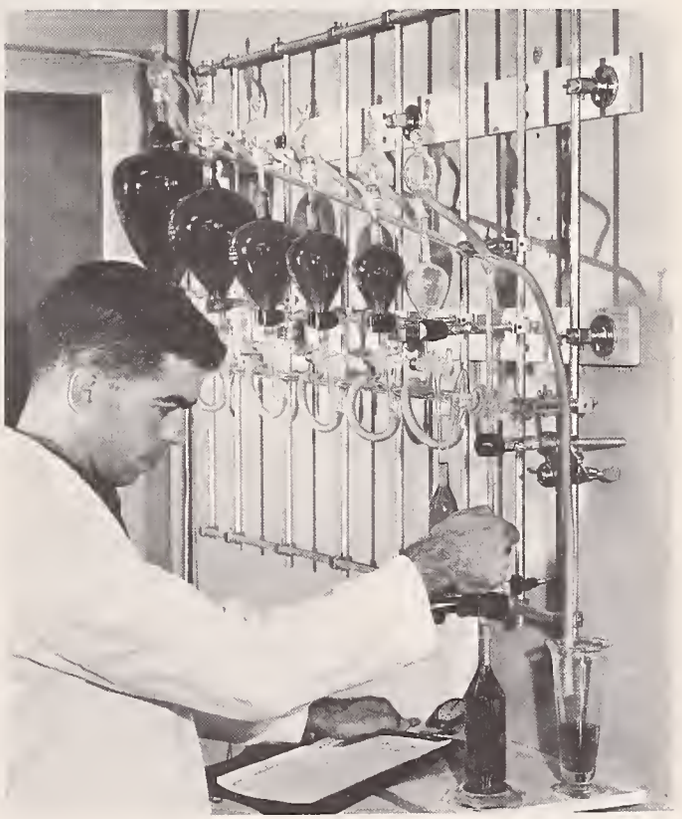
A new form of communication with the weights and measures officials of the Nation, the *Weights and Measures Tech Memo*, was initiated. This memo is issued at practical intervals to selected addresses, principally to State offices. Thus information on significant technical developments is transmitted to the operating level.

A booklet containing simplified test procedures has been prepared for use in the testing of commerical weighing and measuring devices. These procedural outlines list the minimum steps to be followed in an official examination.

New Standards Designed. New mass standards made of stainless steel were recently designed. Orders for a set of metric weights of this design have been placed with manufacturers, as part of a Latin-American Standards development program.

In studies to improve State and industrial equipment, glass capacity measures were developed which are both easy to use and nearly automatic in operation and, at the same time, give highly accurate results; and a 100-gallon stainless steel capacity measure was designed for use as a capacity standard and also for use in the calibration of sanitary meters.

Technical Training. Technical training of State and local weights and measures officials falls into three categories: formal courses of one-week duration for small classes of supervisory personnel in a training laboratory at the Bureau; 2-, 3-, or 4-day formal courses conducted in the various States for all State and local officials; and informal training at the Bureau and in the field to cover laboratory procedures and the use of special testing equipment. Such technical training undoubtedly is a factor in the rapidly developing uniformity and effectiveness of weights and measures regulatory services in the United States. This year, in line with the desire to reach the greatest number of weights and measures officials possible, self-training aids were created as a supplement to the formal training programs.



Standard glass capacity measures recently designed at the Bureau for weights and measures officials are easy to use, nearly automatic in operation, and highly accurate. **(See p. 195.)**

New design for mass standards made of stainless steel. A metric set of this design is being acquired for the Latin American standards program. (See p. 195.)

Technical Information. A basic responsibility is the dissemination of accurate information on units, systems, and equivalents of weights and measures. Tables of interrelation in forms that facilitate ready reference are published, and a large volume of inquiries for technical information is handled every year. Two indexed collections of books—an archival collection and a reference collection—and many historical documents comprise a weights and measures library. This library affords the staff and outside researchers and students complete references on the history and present status of weights and measures.

National Conference on Weights and Measures. The Bureau sponsors an annual National Conference on Weights and Measures where weights and measures officials, representatives of various agencies of the Federal government and of equipment manufacturers and users, and others interested in orderly and effective weights and measures control are assembled for relatively informal meetings. The Conference sessions develop technical and general recommendations for weights and measures administration, contribute to interstate coordination of weights and measures activ-

ity, and explore the entire area of this economically important segment of governmental regulatory service. Among Conference accomplishments are a Model State Law on Weights and Measures, and model regulations covering devices and packages. The Model Law is included among recommended legislative efforts of the Council of State Governments.

At the 48th National Conference held during the year, 39 States, the District of Columbia, Canada, Puerto Rico, England, Austria, and Trinidad and Tobago were officially represented among a total attendance of 499. Principal topics discussed were package standardization and labeling, slow-flow meter tolerances, and rental-car odometer accuracy. Talks were presented on such subjects as the President's Consumer Advisory Council, the International Organization of Legal Metrology, domestic and international business, consumer protection in Great Britain, the Truth in Packaging Bill, and problems in the determination of moisture and quantity control.

3. APPENDIXES

3.1. ORGANIZATION OF THE NATIONAL BUREAU OF STANDARDS*

The Bureau is headed by a Director who is appointed by the President with Senate confirmation. The Director is assisted by two Deputy Directors, one who is responsible for basic standards and services, and the other for technological standards and services. The Associate Directors participate in the leadership function, coordinating related technical work across division lines, heading important policy committees, and handling special assignments in a staff capacity. One of the Associate Directors, in addition to being responsible for administration and support activities of a continuing nature, is in charge of the relocation of the Bureau to new laboratories which are under constuction at Gaithersburg, Maryland. Program activities are conducted in 24 scientific divisions. Most divisions correspond roughly to a major field of physical science or engineering, and are divided into sections responsible for technical areas within each field. Sixteen of the divisions are located in Washington and eight in Boulder. Below the section level, the staff is organized into project groups which may be easily regrouped.

DIRECTOR

Allen V. Astin

DEPUTY DIRECTORS

Robert D. Huntoon
I. C. Schoonover

Associate Directors

L. S. Taylor
R. S. Walleigh
W. A. Wildhack

Manager, Boulder Laboratories

R. B. Scott

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*As of June 30, 1963.

Assistants to the Director

G. E. Auman
W. S. Bussey
W. H. Gammon
A. T. McPherson

Assistant Directors and Senior Research Fellows

U. Fano
K. Shuler

Senior Research Fellows

C. Eisenhart
J. R. Wait

Staff Advisers

Patent Adviser	D. Robbins
Program Adviser	C. N. Coates

NBS WASHINGTON

SCIENTIFIC DIVISIONS AND SECTIONS

(In numerical order)

ELECTRICITY

Chief	C. H. Page
Resistance and Reactance	C. Peterson
Electrochemistry	W. J. Hamer
Electrical Instruments	F. M. Defandorf
Magnetic Measurements	I. L. Cooter
Dielectrics	J. D. Hoffman
High Voltage	F. R. Kotter
Absolute Electrical Measurements	F. K. Harris

METROLOGY

Chief	A. G. McNish
Assistant Chief	D. B. Judd
Photometry and Colorimetry	L. E. Barbrow
Refractometry	F. E. Washer
Photographic Research	C. S. McCamy
Length	T. R. Young
Engineering Metrology	I. H. Fullmer
Mass and Volume	P. E. Pontius

HEAT

Chief	R. P. Hudson
Assistant Chief for Thermodynamics	C. W. Beckett
Temperature Physics	J. F. Swindells
Heat Measurements	D. C. Ginnings
Cryogenic Physics	E. Ambler
Equation of State	J. Hilsenrath
Statistical Physics	M. S. Green

RADIATION PHYSICS

Chief	H. W. Koch
X-ray	H. O. Wyckoff
Radioactivity	W. B. Mann
Radiation Theory	M. Berger, *Acting*
High Energy Radiation	J. E. Liess, *Acting*
Radiological Equipment	S. W. Smith
Nucleonic Instrumentation	L. Costrell
Neutron Physics	R. S. Caswell

ANALYTICAL AND INORGANIC CHEMISTRY

Chief	H. C. Allen
Assistant Chief	R. G. Bates
Consultant	C. P. Saylor
Pure Substances	F. L. Howard
Spectrochemistry	B. F. Scribner
Solution Chemistry	R. G. Bates
Standard Reference Materials	J. L. Hague
Applied Analytical Research	J. K. Taylor
Crystal Chemistry	H. S. Peiser

MECHANICS

Chief	B. L. Wilson
Consultants	J. M. Frankland
	E. C. Lloyd
Sound	R. K. Cook
Pressure and Vacuum	D. P. Johnson
Fluid Mechanics	G. B. Schubauer
Engineering Mechanics	L. K. Irwin
Rheology	R. S. Marvin
Combustion Controls	F. R. Caldwell

POLYMERS

Chief	G. M. Kline
Consultants on Leather	J. R. Kanagy
Paper	R. B. Hobbs
Plastics	S. G. Weissberg
Rubber	L. A. Wood
Textiles	H. F. Schiefer
Macromolecules: Synthesis and Structure	D. McIntyre
Polymer Chemistry	L. A. Wall
Polymer Physics	E. Passaglia
Polymer Characterization	N. P. Bekkedahl
Polymer Evaluation and Testing	R. D. Stiehler
Applied Polymer Standards and Research	R. B. Hobbs
Dental Research	W. T. Sweeney

METALLURGY

Chief	L. M. Kushner
Assistant Chief	G. A. Ellinger
Consultant	L. L. Wyman
Special Assistant	H. C. Burnett
Engineering Metallurgy	S. J. Rosenberg
Metal Reactions	G. A. Ellinger
Metal Physics	L. M. Kushner
Electrolysis and Metal Deposition	A. Brenner

INORGANIC SOLIDS

Chief	A. D. Franklin
Assistant Chief	C. H. Hahner
Consultant	E. R. Lippincott
Vitreous State Group	A. B. Bestul
Engineering Ceramics	M. B. Burdick
Glass	C. H. Hahner
Solid State Chemistry	Vacant
Crystal Growth	F. Ordway
Physical Properties	J. B. Wachtman, Jr.
Crystallography	H. F. McMurdie

BUILDING RESEARCH

Chief	A. A. Bates
Consultant	W. F. Roeser
Structural Engineering	D. Watstein
Fire Research	A. F. Robertson
Mechanical Systems	P. R. Achenbach
Organic Building Materials	W. W. Walton
Codes and Safety Standards	Vacant
Heat Transfer	H. E. Robinson
Inorganic Building Materials	B. E. Foster
Metallic Building Materials	W. N. Harrison

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APPLIED MATHEMATICS

Chief	E. W. Cannon
Assistant Chief	F. L. Alt
Consultants	W. J. Youden
	Mrs. Ida Rhodes
Numerical Analysis	M. Newman
Computation	D. I. Mittleman
Statistical Engineering	J. M. Cameron
Mathematical Physics	W. H. Pell
Operations Research	A. J. Goldman

DATA PROCESSING SYSTEMS

Chief	S. N. Alexander
Technical Assistant	M. R. Fox
PILOT	J. P. Nigro
Research Information Center and Advisory Service on Information Processing	Miss M. E. Stevens
Components and Techniques	R. D. Elbourn
Computer Technology	J. A. Cunningham
Measurements Automation	R. T. Moore
Engineering Applications	J. P. Nigro
Systems Analysis	S. N. Alexander, *Acting*

ATOMIC PHYSICS

Chief	K. G. Kessler
Spectroscopy	W. C. Martin, Jr.
Infrared Spectroscopy	E. K. Plyler
Far Ultraviolet Physics	R. P. Madden
Solid State Physics	H. P. R. Frederikse
Electron Physics	J. A. Simpson
Atomic Physics	H. Boyne
Plasma Spectroscopy	W. L. Wiese

INSTRUMENTATION

Chief	G. F. Montgomery
Engineering Electronics	G. Shapiro
Electron Devices	C. P. Marsden
Electronic Instrumentation	G. F. Montgomery, *Acting*
Mechanical Instruments	A. Wexler
Basic Instrumentation	J. Stern

PHYSICAL CHEMISTRY

Chief	M. B. Wallenstein
Consultants	W. L. Clinton
	E. J. Prosen
Thermochemistry	M. B. Wallenstein
Surface Chemistry	R. Klein
Organic Chemistry	H. S. Isbell
Molecular Spectroscopy	D. E. Mann
Elementary Processes	R. E. Ferguson
Mass Spectrometry	H. Rosenstock
Photochemistry and Radiation Chemistry	J. R. McNesby

OFFICE OF WEIGHTS AND MEASURES

Chief	M. W. Jensen

ADMINISTRATIVE AND SERVICE DIVISIONS

Office of Technical Information	W. R. Tilley
Accounting	J. Seidenberg
Personnel	G. R. Porter
Administrative Services	H. P. Dalzell
Shops	F. P. Brown
Supply	G. B. Kefover
Management Planning	A. J. Muller
Budget	J. E. Skillington
Internal Audit	J. Seidenberg, *Acting*
Plant	M. B. Goetz, *Acting*
NBS Library	Miss S. Jones

BOULDER DIVISIONS

Manager, Boulder Laboratories — R. B. Scott

Consultants

Mathematics Group and Computation Facility	J. J. Sopka
Mathematical Physics and Educational Director	E. H. Brown
Statistics	E. L. Crow
Physics of the Atmosphere	D. M. Gates
Communications Liaison Officer	Allen Barnabei
Executive Officer and Chief of Administrative Division	S. W. J. Welch
Technical Information Officer	J. R. Craddock

CRYOGENIC ENGINEERING LABORATORY

Chief	B. W. Birmingham, *Acting*
Cryogenic Processes	B. W. Birmingham
Cryogenic Properties of Solids	R. H. Kropschot
Properties of Cryogenic Fluids	R. J. Corruccini
Cryogenic Technical Services	V. J. Johnson

CENTRAL RADIO PROPAGATION LABORATORY

Chief	C. G. Little
Assistant Chief	J. W. Herbstreit
Chief, Office of CRPL Liaison and Program Development	A. H. Shapley
Consultant, Radio Wave Propagation	J. R. Wait

IONOSPHERE RESEARCH AND PROPAGATION

Chief	R. W. Knecht
Assistant Chief	T. N. Gautier
Assistant to Chief for Technical Planning and Coordination	J. A. Kemper
Consultants	D. K. Bailey
	H. H. Howe
Ultra Low Frequency Research	W. H. Campbell
Low Frequency and Very Low Frequency Research	A. G. Jean
Ionosphere Research	K. Davies
Prediction Services	Mrs. M. Leftin
Sun-Earth Relationships	T. E. Van Zandt
Field Engineering	H. G. Sellery
Radio Warning Services	Miss J. V. Lincoln
Vertical Soundings Research	J. W. Wright

TROPOSPHERE AND SPACE TELECOMMUNICATIONS

Chief	K. A. Norton
Assistant Chief for Research and Development	R. S. Kirby
Consultant—Terminal Equipment	E. F. Florman
Consultant—Lower Atmospheric Physics	B. R. Bean
Data Reduction Instrumentation	W. E. Johnson
Radio Noise	W. Q. Crichlow
Tropospheric Measurements	M. T. Decker
Tropospheric Analysis	P. L. Rice
Spectrum Utilization Research	A. P. Barsis
Radio Meteorology	R. E. McGavin
Lower Atmosphere Physics	R. E. McGavin, *Acting*

RADIO SYSTEMS

Chief	R. C. Kirby
Assistant Chief	D. W. Patterson
Assistant Chief	W. F. Utlaut
Applied Electromagnetic Theory	J. R. Johler
High Frequency and Very High Frequency Research	L. H. Tveten
Frequency Utilization	G. W. Haydon
Modulation Research	C. C. Watterson
Antenna Research	H. V. Cottony
Radiodetermination	G. Hefley

UPPER ATMOSPHERE AND SPACE PHYSICS

Chief	E. K. Smith, Jr.
Assistant Chief	F. L. Taylor
Consultants	R. J. Slutz
	D. K. Bailey
Upper Atmosphere and Plasma Physics	R. M. Gallet
High Latitude Ionospheric Physics	H. J. A. Chivers
Ionosphere and Exosphere Scatter	K. L. Bowles
Airglow and Aurora	F. E. Roach
Ionospheric Radio Astronomy	R. S. Lawrence

RADIO STANDARDS LABORATORY

Chief	J. M. Richardson
Assistant Chief for Planning and Coordination	E. C. Wolzien
Consultant	D. M. Kerns

RADIO STANDARDS PHYSICS

Chief	Yardley Beers
Assistant Chief	G. E. Hudson
Consultant	P. F. Wacker
Assistant Chief for Technical Planning and Coordination	W. D. Goring
Frequency and Time Dissemination	A. H. Morgan
Radio and Microwave Materials	J. L. Dalke
Atomic Frequency and Time Interval Standards	R. C. Mockler
Radio Plasma	K. B. Persson
Microwave Physics	R. W. Zimmerer, *Acting*

RADIO STANDARDS ENGINEERING

Chief	G. E. Schafer
Assistant Chief	H. W. Lance
Assistant to the Chief for Technical Planning and Coordination	W. J. Anson
Consultants	R. W. Beatty
	M. C. Selby
Coordinator Calibration Service	W. F. Snyder
High Frequency Electrical Standards	C. M. Allred
High Frequency Calibration Services	R. C. Powell, *Acting*
High Frequency Impedance Standards	R. C. Powell
Microwave Calibration Services	R. E. Larson
Microwave Circuit Standards	M. B. Hall
Low Frequency Calibration Services	F. D. Weaver, *Acting*

JOINT INSTITUTE FOR LABORATORY ASTROPHYSICS

NBS GROUP

Chairman	L. M. Branscomb

FIELD ESTABLISHMENTS

Visual Landing Aids Field Laboratory	Arcata, Calif.
Master Railway Track Scale Depot	Clearing, Ill.
Materials Testing Laboratories:	Denver, Colo.
	San Francisco, Calif.
	Seattle, Wash.
Radio Transmitting Station WWV	Greenbelt, Md.
Radio Transmitting Station WWVL	Sunset, Colo.
Radio Transmitting Station WWVL–WWVB	Fort Collins, Colo.

Central Radio Propagation Laboratory Field Stations:

ALASKA
Anchorage
Barrow

ANTARCTICA
Byrd Station**
Eights Station**
Pole Station**
USNS Eltanin (Floating Research Vessel)**

AUSTRALIA
Cook**

BOLIVIA
La Paz**

BRAZIL, S.A.
Sao Jose dos Campos**

CALIFORNIA
Port Arguello

CANADA
Baie St. Paul
Cape Jones**
Great Whale River**
Frobisher Bay**

CHILE
Concepcion**

**Contract or Mutual Cooperation.

COLORADO
Beulah
Brighton
Chalk Cliff Site
Cheyenne Mountain
Erie
Fritz Peak
Green Mountain Mason
Gunbarrel Hill
Haswell
Hygiene
Karval
Kendrick
Kolb
Lafayette
Table Mesa
Sunset

COLOMBIA
Bogota**

GREENLAND
Thule**
Godhavn**
Narssarssuaq**

HAWAII
Maui (WWVH)
Kekaha
Mt. Haleakala

ICELAND
Keflavik**
Reykjavik**

ILLINOIS
Long Branch

INDIA
New Delhi**

JAPAN
Ohira**

KANSAS
Garden City

MALAYA
Singapore**

MISSOURI
Warrensburg

MOROCCO
Rabat**

NEBRASKA
Shickley

NIGERIA
Ibadan**

OKINAWA
Onna**
Okuma**

OKLAHOMA
Altus

PANAMA CANAL ZONE
Balboa**

PERU
Lima**
Jicamarca Radio
Observatory

PHILIPPINE ISLANDS
Baguio

SOUTH AFRICA
Prctoria**

SWEDEN
Enkoping**

UTAH
Salt Lake City**

VIRGINA
Fort Belvoir
Front Royal
Wallops Island

WYOMING
Bill

**Contract or Mutual Cooperation.

3.2. SUMMARY OF NBS STAFF

	Washington	Boulder	Total
Total permanent staff	2,350	1,168	3,518
Other staff*	404	238	642
Total on rolls	2,754	1,406	4,160
Research associates and guest workers	163	34	197
Total on rolls at NBS**	2,917	1,440	4,357
Professional staff***			
Physicists	423	221	644
Chemists	280	7	287
Engineers	166	161	327
Mathematicians	50	59	109
Other	76	19	95
Total professional staff	995	467	1,462

*WAE, consultants, students, teachers, postdoctoral fellows, and temporary-limited employees.
**As of June 30, 1963.
***Full-time permanent (excludes any under *) as of December 31, 1962.

3.3. FINANCIAL DATA ON NBS PROGRAM

The activities of the National Bureau of Standards are financed from three sources: from appropriations provided by the Congress; from payments by other agencies for specific research and development tasks; and from payments by industrial concerns, universities, research institutions, and government agencies for specific calibration or testing services. The following tabulation is a summary of the financial aspects of the Bureau programs for 1963:

Program and source of financing	Obligations incurred (rounded)		
Supported by NBS appropriations:			
Operating programs:			
Research and technical services	$27,782,000		
Special foreign currency program	710,000		
Subtotal		$28,492,000	
Construction and facilities program:			
Plant and facilities	7,204,000		
Construction of facilities	2,423,000		
Subtotal		9,627,000	
Total NBS appropriation			$38,119,000
Supported by other funds:			
Research and development programs:			
Other Federal agencies	14,416,000		
Nongovernmental sources	168,000		
		14,584,000	
Calibrations, testing, standard samples, and other technical services		5,462,000	
Reimbursable administrative services		856,000	
Total supported by other funds			20,902,000
Total program			59,021,000

3.4. ADVISORY COMMITTEES

STATUTORY VISITING COMMITTEE

(Reports annually to Secretary of Commerce on NBS activities (Dates indicate expiration of appointment))

DR. LLOYD V. BERKNER, President, Graduate Research Center, Inc. (1963), Chairman
PROFESSOR FREDERICK SEITZ, President, National Academy of Sciences (1966)
MR. CRAWFORD H. GREENWALT, President, E. I. du Pont de Nemours & Co. (1964)
PROFESSOR CHARLES H. TOWNES, Provost, Massachusetts Institute of Technology (1965)
DR. E. R. PIORE, Vice President, Research and Engineering, International Business Machines Corporation (1967)

TECHNICAL ADVISORY PANELS

At the request of the National Bureau of Standards, the National Academy of Sciences-National Research Council, in cooperation with the leading scientific and technical societies, appoints each year a number of technical advisory panels. The panels make a continuing evaluation of NBS programs with respect to the needs of the Nation's scientific and technological community. The panels provide advice and information in specific technical areas for use by the NBS Director and his staff in the formulation and execution of NBS programs.

Cooperating societies are: American Ceramic Society (ACerS); American Chemical Society (ACS); American Institute of Chemical Engineers (AIChE); Institute of Electrical and Electronic Engineers (IEEE); American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME); American Institute of Physics (AIP); American Society of Civil Engineers (ASCE); American Society of Mechanical Engineers (ASME); and Conference Board of the Mathematical Sciences (CBMS).

Dr. Paul D. Foote, National Research Council, Executive Secretary

Advisory Panel to Electricity Division

Prof. W. A. Lewis, Illinois Institute of Technology, Chairman (IEEE)
Dr. William G. Amey, Leeds & Northrup (IEEE)
Dr. Richard M. Bozorth, Short Hills, N.J. (AIP)
Dr. John Brainerd, University of Pennsylvania (IEEE)
Prof. Henry B. Linford, Columbia University (ACS)
Mr. J. T. Lusignan, The Ohio Brass Company (IEEE)
Prof. John G. Trump, Massachusetts Institute of Technology (AIP)
Dr. Ernest Weber, Polytechnic Institute of Brooklyn (IEEE)

Advisory Panel to Metrology Division

Dr. Brian O'Brien, Pomfret, Conn., Chairman (AIP)
Prof. Isay A. Balinkin, University of Cincinnati (ACerS)
Dr. Alsoph H. Corwin, The Johns Hopkins University (ACS)
Mr. C. L. Crouch, Illuminating Engineering Society (AL)
Mr. A. M. Dexter, Pratt and Whitney Company, Inc. (AL)
Dr. Robert E. Hopkins, University of Rochester (AL)
Mr. Floyd W. Hough, Arlington, Virginia (ASCE)
Dr. Elmer Hutchisson, American Institute of Physics (AIP)
Mr. J. J. Moran, Kimble Glass Company (ACerS)
Mr. Louis Polk, Dayton, Ohio (ASME)
Prof. John Strong, The Johns Hopkins University (AIP)
Dr. J. H. Webb, Eastman Kodak Company (AIP)

Advisory Panel to Heat Division

Prof. Joseph E. Mayer, University of California, Chairman (ACS)
Prof. James A. Beattie, Massachusetts Institute of Technology (AIP)
Prof. Henry A. Fairbank, Duke University (AIP)
Dr. Burgess H. Jennings, Northwestern University (ASME)
Prof. Joseph Kestin, Brown University (ASME)
Dean R. B. Lindsay, Brown University (AIP)
Dr. Charles Squire, Agriculture and Mechanical College of Texas (AIP)
Prof. Glenn C. Williams, Massachusetts Institute of Technology (AICE)

Advisory Panel to Radiation Physics Division

Dr. H. M. Parker, General Electric Company, Chairman (AIP)
Mr. Everitt P. Blizard, Oak Ridge National Laboratory (AIP)
Dr. Martin Deutsch, Massachusetts Institute of Technology (AIP)
Dr. A. O. Hanson, University of Illinois (AIP)
Dr. William A. Higinbotham, Brookhaven National Laboratory (IEEE)
Prof. Harold A. Lamonds, North Carolina State College (IEEE)
Prof. George T. Reynolds, Palmer Physical Laboratory (AIP)
Dr. Leonard Schiff, Stanford University (AIP)

Advisory Panel to Analytical and Inorganic Chemistry Division

Dr. T. Ivan Taylor, Columbia University, Chairman (ACS)
Dr. Clark E. Bricker, The College of Wooster (ACS)
Dr. Norman D. Coggeshall, Gulf Research and Development Company (AIP)
Dr. W. D. Cooke, Cornell University (ACS)
Dr. Herbert A. Laitinen, University of Illinois (ACS)
Dr. W. Wayne Meinke, University of Michigan (ACS)
Prof. Henry Taube, Stanford University (ACS)
Dr. Charles E. White, University of Maryland (ACS)

Advisory Panel to Mechanics Division

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Prof. Lynn S. Beedle, Lehigh University (ASCE)
Prof. Arthur T. Ippen, Massachusetts Institute of Technology (ASCE)
Dr. Harry F. Olson, Radio Corporation of America (AIP)
Prof. Jesse Ormondroyd, University of Michigan (ASME)
Dr. Milton Plesset, California Institute of Technology (AIP)

Advisory Panel to Polymers Division

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Dr. Raymond F. Boyer, Dow Chemical Company (ACS)
Dr. J. H. Dillon, Textile Research Institute (AIP)
Dr. Milton Harris, Harris Research Laboratories, Inc., (ACS)
Dr. Frank C. McGrew, E. I. du Pont de Nemours & Co. (ACS)
Dr. Charles C. Price, University of Pennsylvania (ACS)
Dr. J. F. Downie Smith, Carrier Research and Development Company (ASME)
Dr. Charles Scott Venable, Wallingford, Pa. (ACS)

Advisory Panel to Metallurgy Division

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Dr. D. J. Dienes, Brookhaven National Laboratory (AIP)
Dr. Morris Eugene Fine, Northwestern University (AIME)
Mr. A. R. Lytle, National Academy of Sciences-National Research Council (AIME)
Dr. Oscar Marzke, United States Steel Corporation (AIME)
Prof. E. F. Osborn, Pennsylvania State University (ACerS)
Dr. Joseph A. Pask, University of California (ACerS)
Dr. Albert J. Phillips, American Smelting and Refining Company (AIME)
Mr. D. B. Rossheim, M. W. Kellogg Corporation (ASME)
Mr. J. H. Scaff, Bell Telephone Laboratories (AIME)
Prof. Robb M. Thompson, University of Illinois (AIP)

Advisory Panel to Inorganic Solids Division

Dr. Norbert J. Kreidl, Bausch and Lomb Optical Company, Chairman (ACerS)
Dr. Orson L. Anderson, Summit, New Jersey (ACerS)
Prof. C. Ernest Birchnall, University of Delaware (AL)
Dr. Joseph E. Burke, General Electric Research Laboratory (ACerS)
Dr. James R. Johnson, Minnesota Mining and Manufacturing Company (ACerS)
Prof. J. W. Mitchell, University of Virginia (AL)
Dr. E. F. Osborn, Pennsylvania State University (ACerS)
Dr. Ralston Russell, Jr., The Ohio State University (ACerS)
Mr. Karl Schwartzwalder, General Motors Corporation (ACerS)
Prof. Pierce Selwood, University of California (ACS)

Advisory Panel to Building Research Division

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Prof. Jesse H. Day, Ohio University (ACS)
Dr. Albert G. H. Deitz, Massachusetts Institute of Technology (ASCE)
Dr. J. V. Fitzgerald, Tile Council of America, Inc. (ACerS)
Prof. Robert A. Hechtman, The George Washington University (ASCE)
Prof. James T. Lendrum, University of Florida (AIA)
Dean Warren L. McCabe, Polytechnic Institute of Brooklyn (AICE)
Dr. John S. Parkinson, Johns-Manville Products Corporation (AIP)
Prof. E. R. Queer, The Pennsylvania State University (AL)
Mr. Raymond C. Reese, Toledo, Ohio (ASCE)

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Prof. A. H. Bowker, Stanford University (AL)
Prof. Jesse Douglas, City College of New York (AL)
Prof. William Feller, Princeton University (CBMS)
Dr. Alston S. Householder, Oak Ridge National Laboratory (CBMS)
Prof. B. O. Koopman, Columbia University (CBMS)
Prof. Peter D. Lax, New York University (CBMS)
Dr. Elliott W. Montroll, Institute for Defense Analysis (CBMS)
Prof. R. D. Richtmyer, New York University (CBMS)
Dr. J. Barkley Rosser, Cornell University (CBMS)
Prof. M. M. Schiffer, Stanford University (CBMS)

Advisory Panel to Data Processing Systems Division

Dr. Alston S. Householder, Oak Ridge National Laboratory, Chairman (CBMS)
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Dr. Alan J. Hoffman, International Business Machines Corporation (CBMS)
Mr. John C. McPherson, International Business Machines Corporation (IEEE)
Prof. Charles L. Miller, Massachusetts Institute of Technology (ASCE)
Mr. William Papian, Massachusetts Institute of Technology (IEEE)
Prof. Raymond Pepinsky, Pennsylvania State University (AIP)
Prof. William H. Radford, Massachusetts Institute of Technology (IEEE)
Prof. Morris Rubinoff, University of Pennsylvania (IEEE)

Advisory Panel to Atomic Physics Division

Prof. R. H. Dicke, Princeton University, Chairman (AIP)
Prof. Benjamin Bederson, New York University (AIP)
Dr. Bruce H. Billings, Baird-Atomic, Inc. (AIP)
Prof. Peter Franken, University of Michigan (AIP)
Prof. Jesse L. Greenstein, California Institute of Technology (AL)
Prof. Vernon W. Hughes, Sloane Laboratory (AIP)
Prof. Mark G. Ingham, University of Chicago (AIP)
Dr. Benjamin Lax, Massachusetts Institute of Technology (AIP)
Dr. M. Kent Wilson, Tufts University (ACS)

Advisory Panel to Instrumentation Division

Mr. R. W. Larson, General Electric Research Laboratories, Chairman
Dr. A. O. Beckman, Beckman Instruments, Inc. (AL)
Mr. Ivan G. Easton, General Radio Company (IEEE)
Mr. D. G. Fink, Philco Corporation (IEEE)
Mr. William R. Hewlett, Hewlett-Packard Company (IEEE)
Dr. R. J. Jeffries, Data-Control Systems, Inc. (AL)
Col. J. Z. Millar, Western Union Telegraph Company (IEEE)
Mr. Leon Podolsky, Sprague Electric Company (IEEE)

Advisory Panel to Physical Chemistry Division

Prof. Henry Eyring, University of Utah, Chairman (ACS)
Dr. A. O. Allen, Brookhaven National Laboratory (ACS)
Dr. Paul Cross, Mellon Institute of Industrial Research (ACS)
Dr. Benjamin P. Dailey, Columbia University (ACS)
Dr. Joseph O. Hirschfelder, University of Wisconsin (ACS)
Prof. Hans H. Jaffe, University of Cincinnati (ACS)
Dr. Daniel R. Stull, The Dow Chemical Company (ACS)

Advisory Panel to Cryogenic Engineering Division

Dr. Clyde McKinley, Air Products Incorporated, Chairman (AICE)
Prof. A. L. Hesselschwerdt, Massachusetts Institute of Technology (ASME)
Dr. Hugh M. Long, Tonawanda, New York (AIP)
Dr. Loyd B. Nesbitt, General Electric Laboratory (AIP)
Dr. David White, Ohio State University (ACS)

Advisory Panel to Central Radio Propagation Laboratory

Prof. Arthur H. Waynick, The Pennsylvania State University, Chairman (IEEE)
Mr. Stuart L. Bailey, Alexandria, Va. (IEEE)
Prof. Henry G. Booker, Cornell University (IEEE)
Dr. R. A. Helliwell, Stanford University (IEEE)
Dr. S. W. Herwald, Westinghouse Electric Corporation (IEEE)
Dr. F. S. Johnson, Graduate Research Center (AIP)
Dr. John M. Kelso, ACF Industries, Inc. (IEEE)
Dr. John B. Smyth, Smyth Research Associates (AIP)
Dean George Town, Iowa State University (IEEE)

Advisory Panel to Radio Standards Laboratory

Prof. Arthur A. Oliner, Polytechnic Institute of Brooklyn, Chairman
Dr. Sidney A. Bowhill, University of Illinois (IEEE)
Prof. Walter Gordy, Duke University (AIP)
Prof. E. L. Hahn, University of California (AIP)
Dr. E. W. Houghton, Bell Telephone Laboratories (IEEE)
Prof. E. C. Jordan, University of Illinois (IEEE)
Dr. R. Kompfner, Bell Telephone Laboratories (IEEE)
Prof. W. A. Lewis, Illinois Institute of Technology (IEEE)
Prof. N. F. Ramsey, Harvard University (AIP)
Dr. John C. Simons, National Research Corporation (IEEE)

ADVISORY COMMITTEE ON ENGINEERING AND RELATED STANDARDS

(Members are nominated by the American Standards Association (ASA) and the American Society for Testing and Materials (ASTM))

Mr. W. A. Wildhack, National Bureau of Standards, Chairman
Mr. Roger E. Gay, American Standards Association (ASA)
Mr. Richard T. Kropf, Belding Heminway Company (ASTM)
Mr. John W. McNair, American Standards Association (ASA)
Mr. N. L. Mochel, Westinghouse Electric Corporation (ASTM)
Mr. Frank H. Roby, American Standards Association (ASA)
Mr. Alfred C. Webber, E. I. du Pont de Nemours, Inc. (ASTM)

ADVISORY COMMITTEE ON CALIBRATION AND MEASUREMENT SERVICES

(Members are appointed on the basis of their broad personal knowledge of industrial measurement problems)

Mr. W. A. Wildhack, National Bureau of Standards, Chairman
Mr. Joseph M. Aldrich, San Diego, California
Dr. William G. Amey, Leeds & Northrup Company
Mr. Ivan G. Easton, General Radio Company
Mr. Charles E. Johnson, The Boeing Company
Mr. Sheldon C. Richardson, General Electric Company
Dr. George Sonneman, American Optical Company
Mr. Bruno Weinschel, Weinschel Engineering
Mr. Charles E. White, Avco Research & Advanced Development Division
Mr. L. B. Wilson, Sperry Gyroscope Company

WEIGHTS AND MEASURES ADVISORY COMMITTEE

(Members are nominated by the National Conference on Weights and Measures)

Mr. W. S. Bussey, National Bureau of Standards, Chairman
Miss Genevieve Blatt, Secretary of Internal Affairs, Commonwealth of Pennsylvania
Mr. John Hoyt Chaloud, Ivorydale Technical Center
Mr. C. G. Geiringer, Howe-Richardson Corporation
Prof. L. J. Gordon, Weights and Measures Research Center, Denison University
Mr. Rollin E. Meek, State Board of Health, Indiana
Mr. Donald Malcolm Turnbull, City of Seattle, Comptrollers Department

3.5. AWARDS AND HONORS

Recognition of the Bureau's contributions to science and technology often takes the form of awards and honors from government, academic, professional, and industrial groups. The following list reflects such recognition bestowed on Bureau staff members during fiscal year 1963.

RECIPIENT	AWARD
Bass, Arndld M.	Elected Fellow of Optical Society of America
Bdwles, Kenneth L.	RESA Boulder Scientist Award
Carringtdn, Tucker	Silver Medal of the Combustion Institute
Carter, Thdmas J.	Benedict College Award for Outstanding Achievement
Craig, Norman	William Blum Award of the Electrochemical Society
Davis, Philip J.	Chauvenet Prize of the Mathematical Association of America
Hammdnd, Harry K., III	Award of Merit hy American Society for Testing and Materials
Jackson, Julius L.	Fulbright Scholarship
Jacox, Marilyn E.	Utica College Award for Outstanding Achievement
Mandel, Jdhn	Elected Fellow of the American Association for the Advancement of Science
McIntyre, Donald	Natidnal Capital Award by D.C. Council of Engineering and Architectural Societies
McPherson, Archibald T.	Outstanding Service Award From the Standards Engineers Society and the American Society for Testing and Materials
Meggers, William	Achievement Award of the Spectroscopy Society of Pittsburgh
Newman, Sanfdrd B.	Elected Fellow of the Royal Microscopical Society
Paffenbarger, Gedrge C.	Achievement Medal from Alpha Omega Fraternity
Parsons, Douclas E.	Walter C. Voss Award of the American Society for Testing and Materials
Penner, Samuel	Fellowship from the John Simon Guggenheim Memorial Foundation
Rdsenberg, Samuel J.	Burgess Memorial Award from American Society for Metals
Schiefer, Herbert F.	Honorary Doctor of Science Degree from Ferris Institute
Scribner, Bourdon F.	Elected Honorary Member of Groupement pour l'Advancement Methodes Spectrographiques
Sweeney, William T.	Annual Award of American Academy for Plastics Research in Dentistry
Taylor, Lauriston S.	Orator of the Year of Radiological Society of North America
Wexler, Arnold	Elected Fellow of the Instrument Society of America
Yakowitz, Harvey	Award for Prize Photograph submitted to World Metals Congress of American Society for Metals
Joint Awards:	
Ambler, Ernest Hayward, Raymond W. Hdppes, Dale D. Hudsdn, Ralph P. (Wu, Chien Shiung, Columbia University)	John Price Wetherill Medal from Franklin Institute
Myerson, Melvin R. Ney, Wilbert R. Ydung, Theoddre R.	Charles B. Dudley Medal from American Society for Testing and Materials

HIGHEST NATIONAL BUREAU OF STANDARDS AWARD

RECIPIENT	AWARD
Wait, James R.	Samuel Wesley Stratton Award
Joint Award:	
Bender, Peter L. Driscoll, Raymond L.	Samuel Wesley Stratton Award

DEPARTMENT OF COMMERCE EXCEPTIONAL SERVICE AWARDS

RECIPIENT	TECHNICAL AREA
Brenner, Abner	Electroplating
Cameron, Joseph	Modern statistical and computational methods
Frederikse, Hans P. R.	Solid state physics
Thdmas, Richard N.	Atmospheres of stars

DEPARTMENT OF COMMERCE MERITORIOUS SERVICE AWARDS

RECIPIENT	TECHNICAL AREA
Bean, Bradford R.	Radio wave refraction
Beatty, Robert W.	Microwave circuit standards
Block, Stanley	Analysis of crystal structures
Bussey, Howard E.	Electromagnetic parameters associated with the interaction of electromagnetic waves
Corliss, Charles H.	Quantitative spectroscopy and astrophysics
Hilsenrath, Joseph	Conception and development of OMNITAB
Loving, Vernon W.	Instrument craftsmanship
Mears, Thomas W.	Standard reference materials
Pincock, Glen	Health of NBS staff
Radford, Harrison E.	Molecular energy levels and chemical kinetics
Richmond, Joseph C.	Thermal radiation measurements
Spinner, Sam	Dynamic elastic properties
Stiehler, Robert D.	Standardization of rubber and rubber products
Swanson, Howard E.	Standard x-ray diffraction powder patterns
Woolley, Harold W.	Thermodynamic properties of gases
Joint Award:	
Pruitt, John S.	Standards for determination of total energy content of high energy x-ray beams
Domen, Steve R.	

3.6. EDUCATION AND TRAINING PROGRAM

Available to all staff members at the Bureau is a broad employee development program which is implemented primarily through both the NBS Graduate School and nongovernment educational and training facilities. The program covers educational levels through postdoctoral research. The program is offered at both the Boulder and Washington Laboratories; its primary objectives are the increase of efficiency in the conduct of official assigned duties and the systematic preparation for increased responsibilities.

The Graduate School curriculum includes graduate and undergraduate courses in the physical sciences, mathematics, and certain branches of engineering. Also, a series of scientific colloquia and seminars are led by research leaders from the Bureau staff and from other research centers. In addition, general staff development courses, such as scientific German, practical metallurgy, and mathematical symbolism and terminology, are also offered. Educational counseling is available and employees may receive thesis accreditation for research done at the Bureau.

Since the educational requirements of staff members are varied and changing, the NBS Educational Committee determines course offerings on the basis of periodic need surveys. The program is flexible, including both NBS in-hours courses and NBS-university-sponsored out-of-hours courses. The Technician Career Program, established in 1960, offers a series of in-hours courses on the fundamentals of science and mathematics. The Program helps increase job efficiency and offers educational opportunities to subprofessional laboratory personnel. A workshop in correspondence management, one in filing, and a telephone training course was offered during 1963. Since the establishment of the Washington educational program in 1908, 42 universities have awarded 293 graduate degrees based partly on credits obtained or thesis work carried on under the NBS Graduate School Program.

The Bureau has expanded the Graduate Program at Boulder through the establishment of a Joint-Course program and an Adjoint Professor plan with

the University of Colorado. Various graduate departments at both the NBS Graduate School and the University offer courses simultaneously, with benefits to both the Government and the University. Bureau staff members who teach the courses have the title of Adjoint Professor at the University.

During the summer of 1963, an intensive three-week course in Electromagnetic Measurements and Standards was offered at Boulder in cooperation with the University of Colorado. Participants in the course included not only NBS staff members, but also employees from other government agencies, industry, universities, and foreign research laboratories.

Nongovernment training, authorized by the Government Employees Training Act of 1958, falls into three major categories. These are:

1. Full-time (3 to 12 months) postdoctoral study and research assignments at universities and research centers, both in this country and abroad.

2. Full-time (less than 3 months) attendance at institutes, seminars, short concentrated courses, workshops, etc. Generally, these are offered through the educational facilities of major universities and industrial laboratories throughout the country.

3. Part-time, job-related academic courses at local educational institutions, generally in early evening classes.

Approximately 425 staff members at Washington and Boulder were trained through nongovernment facilities in 1963; fourteen career scientists were selected for full-time research assignments at universities and research centers. Participants in approved full-time nongovernment training programs receive full salary and expenses, including tuition, related fees, travel, and per diem, as well as transportation of family and household effects.

Short concentrated courses and training programs at universities and in industry were attended by forty-six Washington staff members. One hundred thirty-nine Washington employees, mostly from technical divisions, attended job-related courses at local educational facilities.

The Bureau sponsors a student trainee summer program for college students majoring in the physical sciences, mathematics, and certain branches of engineering. Each summer an integrated work-study program including lectures, tours, demonstrations, supervised laboratory assignments, and professional counseling, is conducted. The program acquaints young people interested in career scientific research opportunities with the work being done at NBS. One of the purposes of the program is to help in preparing talented students for scientific careers. The enrollment in the 1963 student program was two hundred thirty-nine students, which included eleven high school students who were winners in the Westinghouse Science Talent Search or other national science contests. The students participating in the program came from schools throughout the country; many of the participants in the program were graduate students.

In collaboration with the National Research Council, the Graduate School offers postdoctoral resident research associateships to young scientific investigators of unusual ability and promise of becoming creative leaders in basic research in the various branches of the physical and mathematical sciences.

While acquiring basic knowledge, they have opportunities to develop new scientific approaches and laboratory skills, and thus advance scientific knowledge. Twenty new Research Associateships (tenable at both the Washington and Boulder Laboratories) are open each year. During 1963, the following young men were selected and served: Stanley Abramowitz, Robert L. Brown, Halbert H. Carmichael, George E. Chamberlain, Richard F. Demar, James E. Faller, Marcel L. Halberstadt, Eugene C. Johnsen, Robert H. Kastl, David M. Larsen, Joseph A. Pirog, Duncan E. Poland, Albert Romano, Joe D. Simmons, Robert E. Simpson, John W. Stewart, Tannie Stovall, Joseph L. Thompson and George H. Thomson.

Scientific staff meetings, held weekly from September through May, are also included in the Bureau's educational program. The staff meetings are of a less specialized nature than colloquia and seminars offered in the Graduate School program. They are open to all professional staff members of the Bureau and to scientific personnel from neighboring laboratories.

3.7. PUBLICATIONS* AND PATENTS

Publications in the Bureau's Series

Journal of Research. Contains full research papers, including laboratory data, experimental procedures, and theoretical and mathematical analyses. Advances in measurement standards and techniques . . . physical constants . . . properties of materials . . . instrumentation . . . radio propagation.

The Journal is published in four separate sections . . .

A. Physics and Chemistry, issued six times a year. Annual subscription: Domestic, $4; foreign, $4.75. Single copy, 70 cents.

B. Mathematics and Mathematical Physics, issued quarterly. Annual subscription: Domestic, $2.25; foreign, $2.75. Single copy, 75 cents.

C. Engineering and Instrumentation, issued quarterly. Annual subscription: Domestic, $2.25; foreign, $2.75. Single copy, 75 cents.

**D. Radio Propagation, issued six times a year. Single copy, 75 cents.

The papers listed below have appeared in the four-section Journal since June 1962.

Volume 66A (Phys. and Chem.), No. 4 (July–Aug. 1962)

Dielectric properties of semicrystalline polychlorotrifluoroethylene. A. H. Scott, D. J. Scheiber, A. J. Curtis, J. I. Lauritzen, Jr., and J. D. Hoffman.

Thermal degradation of fractionated high and low molecular weight polystyrenes. S. L. Madorsky, D. McIntyre, J. H. O'Mara, and S. Straus.

Synthesis of 2-propoxy-5-methylbenzoic acid. G. M. Brauer and L. Simon.

The gamma-ray distribution from oriented cerium-141. J. F. Schooley, D. D. Hoppes, and A. T. Hirshfeld.

Light source for producing self-reversed spectral lines. J. Sugar.

A diamond cell for X-ray diffraction studies at high pressures. G. J. Piermarini and C. E. Weir.

Thermal conductivity of gases. I. The coaxial cylinder cell. L. A. Guildner.

Thermal conductivity of gases. II. Thermal conductivity of carbon dioxide near the critical point. L. A. Guildner.

Derivation of the relaxation spectrum representation of the mechanical response function. R. S. Marvin.

Intermediate phases in superconducting niobium-tin alloys. L. L. Wyman, J. R. Cuthill G. A. Moore, J. J. Park, and H. Yakowitz.

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*Publications for which a price is indicated are available by purchase from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402 (foreign postage, one-fourth additional). Reprints from outside journals and the NBS Journal of Research may often be obtained directly from the authors.

** Changed to *Radio Science* in January 1964, issued monthly. Annual subscription: Domestic, $9; foreign, $11.50. Single copy, $1.00.

Methods of measuring the resistivities of anisotropic conducting media in situ. S. Rush.
Corrosion of steel pilings in soils. M. Romanoff.
Corrosion rates of ferrous alloys (Fe-Cr and Fe-Cr-Si) measured by polarization technique. W. J. Schwerdtfeger.
A furnace for thermocouple calibrations to 2,200 °C. D. B. Thomas.
Total hemispherical emittance of coated and uncoated Inconel and types 321 and 430 stainless steel. J. C. Richmond and W. N. Harrison.
"Mail Separator" control computer preliminary logical design. S. Henig and E. C. Palasky.
Method of measuring emissivities of metals in the infrared. A. G. Maki and E. K. Plyler.

Volume 66C (Eng. and Instr.), No. 4 (Oct.–Dec. 1962)

An ultra-high speed image dissecting camera for photographing strong shock waves. K. B. Earnshaw and C. M. Benedict.
Biprism method of determining the equivalent focal length of flat field lenses. W. R. Darling.
Effect of air drag on the motion of a filament struck transversely by a high-speed projectile. F. L. McCrackin.
A precision noise spectral density comparator. C. M. Allred.
Stresses in a plate uniformly compressed over portions of its two opposite edges. M. Chi and W. D. Kroll.
Studies of the stress-corrosion cracking of low-carbon steels. H. L. Logan.
A dual centrifuge for generating low-frequency sinusoidal accelerations. R. O. Smith, E. A. Willis, and J. S. Hilten.
Rotational micromanometers. K. Lofquist.
Study of gypsum plasters exposed to fire. J. V. Ryan.

Volume 67C (Eng. and Instr.), No. 1 (Jan.–Mar. 1963)

Method for calibrating a standard volt box. B. L. Dunfee.
Stability of residual thiosulfate in processed microfilm. C. I. Pope.
Equipment for single crystal growth from aqueous solution. J. L. Torgesen, A. T. Horton, and C. P. Saylor.
An automatic multichannel correlator. R. F. Brown, Jr.
Elastic constant—porosity relations for polycrystalline thoria. S. Spinner, F. P. Knudsen, and L. Stone.
An oxygen partial pressure warning instrument. L. Greenspan.
New fast-opening, large-aperture shutter for high-speed photography. E. C. Cassidy and D. H. Tsai.
Equations for the radiofrequency magnetic permeameter. C. A. Hoer and A. L. Rasmussen.

Volume 67C (Eng. and Instr.), No. 2 (Apr.–June 1963)

Temperature dependence of the elastic constants of thoria specimens of varying porosity. S. Spinner, L. Stone, and F. P. Knudsen.
Residual stresses and their relaxation on the surfaces of sections cut from plastically deformed steel specimens. Clarence J. Newton.
Permeation rates of electrolytic hydrogen and deuterium through iron. Joseph W. Pitts.
Steady state heat conduction in cylinders with multiple continuous line heat sources. B. A. Peavy.
A radial-flow apparatus for determining the thermal conductivity of loose-fill insulations to high temperatures. D. R. Flynn.
Analysis of a microwave radiometer for precise standardization of noise sources. Gray D. Ward and John M. Richardson.
Realistic evaluation of the precision and accuracy of instrument calibration systems. Churchill Eisenhart.

Volume 66D (Radio Prop.), No. 4 (July–Aug. 1962)

Propagation problems with space radio communications. K. Rawer.
On the absolute intensity of incoherent scatter echoes from the ionosphere. K. L. Bowles, G. R. Ochs, and J. L. Green.
On the forward scattering of radio waves in the lower ionosphere. T. Hagfors.
Representation of diurnal and geographic variations of ionospheric data by numerical methods. W. B. Jones and R. M. Gallet.
Interaction between an obliquely incident plane electromagnetic wave and an electron beam in the presence of a static magnetic field of arbitrary strength. K. H. B. Wilhelmsson.

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An analysis of VLF mode propagation for a variable ionospheric height. J. R. Wait.
A method for the determination of lower ionosphere properties by means of field measurements on sferics. F. B. Harris, Jr., and R. L. Tanner.
Defocusing of radio rays by the troposphere. R. E. Wilkerson.
Magnetotelluric fields in the frequency range 0.03 to 7 cycles per kilosecond: Part I. Power spectra. C. W. Horton and A. A. J. Hoffman.
Magnetotelluric fields in the frequency range 0.03 to 7 cycles per kilosecond: Part II. Geophysical interpretation. C. W. Horton and A. A. J. Hoffman.
Impedance of a circular loop in an infinite conducting medium. M. B. Kraichman.

Volume 66D (Radio Prop.), No. 5 (Sept.–Oct. 1962)

Theory of magneto-telluric fields. J. R. Wait
Propagation characteristics of magneto-ionic plasma columns. D. Formato and A. Gilardini.
Dielectric loading of electric dipole antennas. J. Galejs.
Possible influence of the ionosphere on the impedance of a ground-based antenna. J. R. Wait.
Some statistical theory for the analysis of radio propagation data. M. M. Siddiqui.
Auroral sporadic-*E* ionization. R. D. Hunsucker and L. Owren.
Comparative study of the correlation of seasonal and diurnal cycles of transhorizon radio transmission loss and surface refractivity. B. R. Bean, L. Fehlhaber and J. Grosskopf.
Enhancement of the lunar tide in the noon critical frequency of the F_2 layer over the magnetic equator. R. G. Rastogi.
Scattering from a conducting sphere embedded in a semi-infinite dissipative medium. J. Galejs.
High-frequency scattering from a coated sphere. V. H. Weston and R. Hemenger.
Propagation of spherical waves through an ionosphere containing anisotropic irregularities. K. C. Yeh.

Volume 66D (Radio Prop.), No. 6, (Nov.–Dec. 1962)

RF impedence probe measurements of ionospheric electron densities. J. A. Kane, J. E. Jackson, and H. A. Whale.
Methods for applying numerical maps of ionospheric characteristics. W. B. Jones and R. M. Gallet.
Very-low-frequency radio propagation in the ionosphere. D. W. Swift.
Prolonged space-wave fadeouts in tropospheric propagation. A. P. Barsis and M. E. Johnson.
Range-error compensation for a troposphere with exponentially varying refractivity. J. J. Freeman.
On the geometrical optics of curved surfaces with periodic impedance properties. C. J. Marcinkowski and L. B. Felsen.
On the limitations of geometrical optics solutions for curved surfaces with variable impedance properties. C. J. Marcinkowski and L. B. Felsen.
Conversion of the amplitude-probability distribution function for atmospheric radio noise from one bandwidth to another. A. D. Spaulding, C. J. Roubique, and W. Q. Crichlow.
Some statistical properties of pulsed oblique HF ionospheric transmissions. M. Balser and W. B. Smith.
Induction in a small loop moving with a magnetostatic dipole toward a conducting half space. M. B. Kraichman.
Propagation of terrestrial radio waves of long wavelength—theory of zonal harmonics with improved summation techniques. J. R. Johler and L. A. Berry.
Terminal-zone corrections for a dipole driven by a two-wire line. K. Iizuka and R. W. P. King.
Pattern synthesis with a flush-mounted leaky-wave antenna on a conducting circular cylinder. A. Ishimaru and F. R. Beich.

Volume 67D (Radio Prop.), No. 1 (Jan.–Feb. 1963)

"A lunar theory reasserted"—a rebuttal. J. V. Evans.
Point-to-point communication on the moon. L. E. Vogler.
HF communication during ionospheric storms. G. E. Hill.
Use of surface refractivity in the empirical prediction of total atmospheric refraction. W. R. Iliff and J. M. Holt.
Effective sunspot numbers, January 1961 through July 1962. W. B. Chadwick.
On the theory of radio wave propagation over inhomogenous earth. K. Furutsu.

Correction to "Fields of electric dipoles in sea water, the earth-atomsphere-ionosphere problem". W. L. Anderson.
Composition of reflection and transmission formulae. J. Heading.
Titheridge coefficients for the polynomial method of deducing electron density profiles from ionograms. A. R. Long and J. O. Thomas.
Input admittance of linear antennas driven from a coaxial line. T. T. Wu.

Volume 67D (Radio Prop.), No. 2 (Mar.–Apr. 1963)

The protection of frequencies for radio astronomy. R. L. Smith-Rose.
Radar reflections from the moon at 425 Mc/s. G. H. Millman and F. L. Rose.
Sunset and sunrise in the ionosphere: effects on the propagation of longwaves. J. Rieker.
Correction of atmospheric refraction errors in radio height finding. W. B. Sweezey and B. R. Bean.
Empirical determination of total atmospheric refraction at centimeter wavelengths by radiometric means. A. C. Anway.
Propagation of radiofrequency electromagnetic fields in geological conductors. V. Fritsch. Translated from German by A. P. Barsis.
WWV reception in the arctic during ionospheric disturbances. G. E. Hill and John R. Herman.
Height-gain for VLF radio waves. J. R. Wait and K. P. Spies.
Perturbation method in a problem of waveguide theory. D. Fox and W. Magnus.
Some wave functions and potential functions pertaining to spherically stratified media. C. T. Tai.
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Effects of radio wave propagation through mid-latitude 6300 A auroral arcs. J. R. Roach.
Comparison of observed atmospheric radio refraction effects with values predicted through the use of surface weather observations. B. R. Bean and G. D. Thayer.
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Impedances of long antennas in air and in dissipative media. D. W. Gooch, C. W. Harrison, Jr., R. W. P. King, and T. T. Wu.
Reflection of VLF radio waves from an inhomogenous ionosphere. Part I. Exponentially varying isotropic model. James R. Wait and Lillie C. Walters.

Technical News Bulletin. This monthly publication summarizes the current research, development, and test activities of the Burcau. The articles are brief, with emphasis on the results of research and their significance, chosen for their importance to other scientists, engineers, and to industry. Résumés of longer research reports, important national and international conferences on fudamental science in which the Bureau has represented the Nation, and bibliography of all publications by members of the staff as published are included. The Bulletin is designed to give a succinct account of the current work of the Bureau. (Annual subscription: domestic, $1.50; foreign, $2.25.)

Central Radio Propagation Laboratory Ionospheric Predictions: This is a monthly publication for those concerned with radio communication in determining the best skywave frequencies over any path at any time of day for avcrage conditions for the month of prediction, which are made 3 months in advance. Charts of extraordinary-wave critical frequency for the $F2$ layer and of maximum usable frequency for a transmission distance of 4,000 km, of highest frequency of sporadic E in excess of 15 Mc/s are included. In addition, there are various maps, charts, diagrams, and nomograms needed to make practical application of the world-contour charts, together with examples of their use. (Annual subscription: domestic, $1.50; foreign, $2.00.)

Monographs. These are usually contributions to the technical literature which are too lengthy for publication in the Journal of Research. They often provide extensive compilations of information on subjects related to the Bureau's technical program. Until July 1959 most of this type of material was published in the Circular series.

25. Standard X-ray diffraction powder patterns. Section 2. Data for 37 substances, H. E. Swanson, M. C. Morris, R. P. Stinchfield, and E. H. Evans. May 3, 1963. 35 cents.
43. Chemistry of cement, Proceedings of the Fourth International Symposium, Washington 1960, Volume I. August 31, 1962, $6.50; Volume II. September 27, 1962. $6.25.
49. Tables of Einstein functions, vibrational contributions to the thermodynamic functions, J. Hilsenrath and G. G. Ziegler, July 12, 1962. $2.75.
50. Bibliography on atomic transition probabilities, B. M. Glennon and W. L. Wiese, August 1, 1962. 35 cents.
51. Analysis of electric energy usage in Air Force houses equipped with air-to-air heat pumps, P. R. Achenbach, J. C. Davis, and W. T. Smith. July 13, 1962. 30 cents.
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53. Experimental transition probabilities for spectral lines of seventy elements, C. H. Corliss and W. R. Bozman, July 20, 1962. $4.25.
54. Analytical standards for trace elements in petroleum products, H. S. Isbell, R. S. Tipson, J. L. Hague, B. F. Scribner, W. H. Smith, C. W. R. Wade and A. Cohen, October 1, 1962. 25 cents.
55. NBS viscometer calibrating liquids and capillary tube viscometers, R. C. Hardy. December 26, 1962. 20 cents.
56. Systems of electrical units, F. B. Silsbee. September 20, 1962. 30 cents.
57. Periodicals received in the Library of the National Bureau of Standards, July 1962, N. J. Hopper, November 23, 1962. Supersedes NBS Circular 563 and the 1st Supplement to NBS Circular 563. 25 cents.
58. Corrosion of steel pilings in soils, M. Romanoff, October 24, 1962. 20 cents.
59. Mechanical behavior of crystalline solids, Proceedings of an American Ceramic Society Symposium, New York City, April 1962. March 25, 1963. $1.75.
60. Influence of a sector ground screen on the field of a vertical antenna, J. R. Wait and L. C. Walters. April 15, 1963. 25 cents.
62. Testing of metal volumetric standards, J. C. Hughes and B. C. Keysar. April 1, 1963. 15 cents.
63. Tensile and impact properties of selected materials from 20 to 300° K, K. A. Warren and R. P. Reed. June 29, 1963. 35 cents.
64. Refractive indices and densities of aqueous solutions of invert sugar, C. F. Snyder and A. T. Hattenburg. June 7, 1963. 15 cents.
65. Reduction of data for piston gage pressure measurements, J. L. Cross. June 17, 1963. 15 cents.

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244. Report of the 47th National Conference on Weights and Measures 1962. November 23, 1962. 75 cents.
245. Hydraulic research in the United States, 1962, H. K. Middleton. October 26, 1962. $1.00.
246. Research highlights of the National Bureau of Standards, Annual Report 1961. December 1962. 70 cents.

Handbooks. These are recommended codes of engineering and industrial practices, including safety codes, developed in cooperation with the national organizations and others concerned. In many cases the recommended requirements are given official status through their incorporation in local ordinances by State and municipal regulatory bodies.

83. Tabulation of data on receiving tubes, C. P. Marsden and J. K. Moffitt. May 23, 1963 (supersedes Handbook 68). $1.25.
84. Radiation quantities and units. International Commission on Radiological Units and Measurements (ICRU) Report 10a, 1962. November 14, 1962. 20 cents.
88. Radiobiology dosimetry. Recommendations of the International Commission on Radiological Units and Measurements (ICRU) Report 10e, 1962. April 30, 1963. 25 cents.
90. Handbook for CRPL Ionospheric Prediction based on numerical methods of mapping, S. M. Ostrow. December 21, 1962 (supersedes Circular 465). 40 cents.

Technical Note Series. This series was initiated in 1959 to supplement the Bureau's regular publications program. Technical Notes provide a means for making available scientific data that are of transient or limited interest.

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PATENTS

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